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1.—Australian Aborigines: Research and Welfare

Presidential Address, 1973

by Ronald M. Berndt¹

Delivered 16 July, 1973

Abstract

Reference to an article in the first issue of this *Journal* points up changes in Aboriginal living conditions and in Australian society generally, and also in research methods. The main features of traditional Aboriginal society are outlined. They influenced the Aborigines' reactions to the European invaders as well as *vice versa*. Only when these features were modified was rapprochement possible, but it was a one-way process. Today, despite appearances to the contrary, the Aborigines are actually more dependent on others than ever before, and welfare policies and practice take even less account of solid research findings. Moreover, the new Aboriginal identity is being shaped in a context where the traditional past is a source of inspiration but provides few guide lines for the future.

I

A presidential address is not intended simply to illuminate a particular topic from the angle of a particular academic discipline. It should also say something about the contribution of the Society (in this case, the Royal Society of W.A.) in relation to that topic. It is interesting therefore to note that when this Society emerged (in 1914) from the Natural History and Science Society, under the guiding hand of Professor W. J. Dakin, Vol. I of its *Journal and Proceedings* for 1914-15 contained an article on Sunday Island by W. D. Campbell and W. H. Bird (1916: 55-82). Bird was a teacher at the mission settlement which had been established among the Bard people in 1899. It is not a professional anthropological contribution, but it points up obliquely some of the things I shall be talking about. For instance, it underlines the tremendous changes in research methods that have taken place over the years. It reflects the contrast between then and now in another sense too. The small, quiet settlement at Sunday Island was run primarily on private funds, with a government allowance of blankets and ninepence per day for the aged and infirm. The State Education Department made a grant of £100 a year to the mission school.

In that span of almost sixty years, it is as if another world has been superimposed on the old, but in such a way that the old one has not been entirely eradicated—at least, not yet. In general, those years have seen much fluctuation both in policies and in practice. They have also seen the movement of Aborigines from being an inarticulate, almost invisible minority, to a vociferous, highly visible and expanding population.

One focus of attention in this State, both then and now, has been the economic activities

of the Bard. As Campbell and Bird noted, these people were concerned with marine products. Today, the Ecology Unit under Commonwealth financial support and guidance is endeavouring to establish a turtle-farming venture, because the Bard are heavily dependent on outside help. But in 1914 and before, they were economically viable, with their pearlshell and *bêche-de-mer* fishing. The theme of outside concern is the same, but the local circumstances are not.

II

If the gap between the early Bard example and the contemporary situation is so considerable, the gap between traditional Aboriginal life and what survives now, not only among the Bard but also more generally, is even wider. We could almost say that it was a world apart from Aboriginal life as it exists today.

Aside from the question of attitudes on the part of early European settlers toward non-Europeans in general, attitudes which are fairly well documented, the immense difference in life-styles between the newcomers and the Aborigines made any real rapprochement between them very difficult indeed, if not actually impossible. These difficulties became increasingly evident soon after initial contact, as both peoples became more conscious of pervasive incompatibilities. They have been modified only through an ironing-out or blurring of traditional Aboriginal elements. For a long time, these differences were seen as a contrast between "civilized" and "uncivilized", between "sophisticated" and "primitive" man. But this was a biased and faulty interpretation, one that could not stand up to closer scrutiny. Traditional Aboriginal societies and cultures were highly complex. Their members were ordinary, intelligent human beings, guided by their own belief systems and their accepted behavioural patterns. The organization of their societies was different from ours, and so were their values: their aims were not the same. The positive qualities of their way of life were not immediately obvious to outsiders who were used to a very dissimilar social and economic setting, with its stress on material goods and its thing-oriented technology.

The Aborigines were on the whole a deeply religious people. Religious feeling was manifested through ritual observance and through mythic expression: it was really something that was taken for granted. In essence, it was based on a deep and emotional attachment to the land. That land was to them full of signs, which had a direct relevance to socio-economic living.

¹ Presidential address delivered July 16th, 1973.

It was a land made familiar and intimate to them through mythic beings who were believed to be manifested at specific sites, beings who were believed to be always present and to be approachable through the medium of ritual. These were eternal or enduring elements, underlining continuity sustained through religious practice. They emphasized the fundamental unity of the human and the natural-physical environment, a kind of empathy between man and all natural species and phenomena. Everything was, at one conceptual level, brought together into one expanded socio-cultural environment, so that man was not seen as opposed to nature but as working in harmony with it. This was expressed through the concept of the Dreaming, as it is sometimes called in translation, in which all the most significant aspects of life were believed to have been set in motion by the primary mythic and spirit beings. The deities were manifested through man, and other living things and other features were selected as intermediaries or symbolic representations: all drew on the same life force. This particular relationship to the land and all within it was phrased as a total dependence upon it: and the way this was wrapped up in socio-cultural terms provided an emotional assurance that helped people to cope with such natural crises as drought or floods, and the human crisis of physical death. It was a screen between them and the stark reality of such crises, helping them to feel that their survival did not rest solely on their skills, their few weapons and techniques: the mythic beings stood protectively between them and any potential disaster, as a buffer or an intermediary, a source of confidence as well as a source of traditional guides to practical procedures.

But living and making a living involved also relations between people. In short-range terms, any Aboriginal man and his immediate family could live off the land quite capably under normal seasonal conditions. However, the fuller round of events called for a wider range of people. This meant that the range of dependence was extended, highlighting the issues of reciprocity and responsibility for others that were the basis of group existence. The large kin-oriented structures which were usual in Aboriginal Australia had a specifically utilitarian (or socio-economic) value. They represented a buffer of a different sort, a non-mythic or non-ritual buffer, between every Aboriginal person and the demands of his physical environment. Co-operation with others was an essential part of Aboriginal semi-nomadic living. Kinship networks linked people together, in combinations that sometimes took the form of conflict but more often emphasized collaboration and mutual help. Within a certain regional span, a person could always be sure of having relatives who could more or less be relied on to take his part—not necessarily the same people in all circumstances; but there were always some to defend or support him.

The genius of traditionally-oriented Aborigines rested primarily on their ability to organize,

providing an assured though reasonably flexible programme for co-operation in everyday affairs, and a religious belief system which substantiated a life within surroundings that were familiar but full of interest and meaning. It is a mistake to believe that this life was unduly monotonous or consisted of repetitive action within a circumscribed and limited frame of belief.

It is true that traditional Aboriginal life was cast within the mould of the past; what had been proven then, or believed to have been proven, was considered to have a direct bearing on the present: the lessons learnt from the past could be applied effectively to the present and to the future, if for no other reason than that solutions to specific problems of living within the Australian environment could not be varied radically—not without risk.

Outside the dynamics of social living—in, for example, domestic relations, marriage, children growing up and being initiated, confronting the inevitability of death—outside of these, religious rituals were essentially concerned with renewal, with spiritually stimulating environmental fertility, and with sharpening intellectual faculties. In that respect, ritual provided the main stimulus to enquiry and speculation. Such enquiry took place within what can be called a closed system, but it was not entirely straight-jacketed. It nurtured and enriched the Aboriginal arts—music, song-poetry and oral literature generally, dancing, painting and sculpture. Evaluating a society or a culture solely in terms of what people do to gain a livelihood provides only a one-sided appraisal. In all human societies there are particular imperatives which cannot be evaded if survival is to be ensured. However, what people do *outside* that sphere of necessity is especially significant. As far as the Aborigines are concerned, the great mythic epics and song cycles demonstrate beyond doubt a high level of cultural attainment: they thought and felt and expressed themselves poetically in ways which were mediated not only through religion but also through ordinary living. I am reminded of what Strehlow (1971: 247) has pointed out, and others too: that anyone conversing with fully-initiated Aboriginal men “trained in speech by means of the sacred myths and songs” cannot fail to be aware that he is in the presence of men of education and culture.

Against this picture of relative harmony and environmental adjustment and intellectual development, there are inevitably many examples of human fallibility. Life could be harsh, social relations were fraught with difficulties, and the ordinary course of living was punctuated by interpersonal dissension. It was not a utopian existence. It does seem that the basic needs of Aboriginal man were reasonably satisfied, that people were able to achieve a fair degree of happiness and comfort. But limitations were imposed. Even if they were not directly recognized, they were definitely present. Independence—individual independence—was played down, or undervalued, because group co-operation was an economic necessity; and speculation

and experiment could go only so far, because the *status quo* depended on common expectations in belief and in action. In balance, however, there were more positive attributes: values related to a perceived affinity with the land, harmony with nature, co-operativeness, a love of beauty and aesthetic appreciation, a respect for the past which provided an assurance for the future, and recognition of personal rights viewed as affecting others—recognition that a person is responsible to others as those others are responsible to him. These values were either ignored or not appreciated by the European newcomers.

III

The traditional Aboriginal aspects which I have noted in summary must be taken into account if we are to appreciate the results of alien impact. They have to be understood, too, in relation to the creation of a social identity for Aborigines in today's scene.

It was this traditional world of the Aborigines which, in so many instances, received a death-blow when it came into contact with outsiders. In the southern and south-eastern areas, where European settlement expanded rapidly, it meant the complete destruction of the Aboriginal way of life and, in a number of cases, of the people themselves as well. That history is so much a part of our own that there is no need for me to sketch it out in any detail. Three points only need be mentioned.

One: there was, as soon as Aborigines realized that the aliens had come to stay, a great deal of opposition to this intrusion, especially when their lands were appropriated without reference to them and their food resources were threatened. Literally, many were obliged to fight for their very existence. But they were ill-equipped for that purpose and lacked one of the fundamental pre-requisites—that is, political strategy and an overarching institution which would have enabled them to muster a large opposition force. I said that their genius rested on organization—but not on such a large scale, and not for collective aggressive acts of offence and defence. They depended instead on skirmish and on ruse, on guerilla warfare. What occurred in the Swan River Colony between 1830-1840 bears this out, as it does in other areas. The "Battle of Pinjarra", as it has been called, was not a battle at all. The Aborigines concerned, including women and children, were not ready to fight. It was an ambush on the part of the Europeans, and there was little opportunity for any Aborigines to escape through the cross-fire of the two parties. Such instances were duplicated, in one way or another, so that capitulation was only a matter of time and was the only course open to Aborigines—not in the spirit of "if you're being licked by them, join them", but simply because no other alternative existed. In the long run, those who did survive "joined them" (that is, the Europeans).

This brings me to my second point. To "join them" meant that Aboriginal traditional life had to be considerably modified. For instance, by the 1880's, in the south-west of this State, that

traditional life had disappeared as a living, functional reality. In the process, the indigenous population was almost entirely replaced by a part-Aboriginal population—a few of them directly descended from the original local people, but most of considerably mixed Aboriginal affinity. Again, that situation was duplicated in New South Wales, Victoria, South Australia, and so on—except, of course, in Tasmania: the story there is not all that different, only more extreme.

The third point relates to the unevenness of alien contact. Not all Aborigines were affected in this way. But eventually, as time went on, all were exposed in varying degrees to external pressures, and their reactions to these differed. However, because of this unevenness, much of traditional life survived in some areas—at first in its traditional form, but increasingly with considerable modifications. The last great socio-cultural reservoirs, so to speak, have been Arnhem Land and the Western Desert—or they were, until just after the second world war.

Wherever contact with outsiders took place, and irrespective of policies promulgated or put into action—whether on government or mission settlements, on pastoral stations, in country or "fringe" towns or in cities—wherever such contact took place, the theme of "civilizing" was emphasized: and to Europeans, "civilization" meant "Europeanization". Accordingly, Aborigines of all kinds were persuaded, directly or indirectly, to become more Europeanized, and, what was most important in this process, to learn new work patterns and adopt a new economic pattern of living. Although welfare policies varied over the years, from advocating separate development or from "smoothing the dying pillow" to inevitable assimilation, all involved increasing European control and influence—most of which ignored or discredited the importance of Aboriginal life or what remained of it. The Aborigines, so it was said, had little to offer. Europeans, on the other hand, had everything to give—but at a price. This state of imbalance was actively encouraged, and coloured virtually all of Aboriginal-European interaction. It developed a pronounced state of dependence. It also had repercussions which have extended into the present-day scene. What emerged from this—with only a few, very few, exceptions—was that the Aborigines were reduced to an almost invisible, almost inaudible, segment of the Australian population. The radical diminishing of their independence, the removal of land from their control, the downgrading of religious belief: all of these, along with others, led inevitably to their socio-cultural impoverishment.

In the "outside world", being of Aboriginal descent had no positive value at all, only a negative one. The hard road toward a "new" culture with its new social implications was strewn with obstacles, tangible and intangible, which most Aborigines were unable to overcome. There is no need for me to spell this out, and in relation to specific local groups the space-time component varied considerably. For instance, although this state of affairs existed

almost from the onset of alien contact, it is still observable today in a number of country towns in Western Australia, among other places. Opportunities for breaking this vicious circle are much greater now, but the process is still a traumatic and difficult one for the people concerned. The extension of Australian citizenship to Aborigines came only gradually, and for a long time meant very little to them. Special regulations affecting them were originally designed to protect and safeguard them, as a people in special need of protection and guidance, but too often they became almost ends in themselves. Welfare and advancement ideals became bogged down in a welter of prohibitions. And it was only too clear that protective policies were not there solely to protect Aborigines; they were also designed, or used, to protect non-Aboriginal interests. I won't speak of exploitation in this respect, except to say that it was not only present but was also actively encouraged in a number of instances—especially in some pastoral areas of the Kimberleys and the Northern Territory, as well as elsewhere.

The problems *vis-à-vis* Aborigines, resulting on one hand from external contact and on the other from their own attempts to sustain rapidly changing traditional patterns—these problems ramified and could not be resolved without drastic action which, in turn, had further repercussions. To mention only three of these: (a) economic deprivation; (b) restricted educational opportunities and restricted opportunities for acquisition of basic skills; and (c) the eroding influence of drinking to excess. These issues alone were sufficient to define the Aborigines' position within the wider community; (a) and (b) were complementary, one upholding and reinforcing the other. Low socio-economic status confined groups of Aborigines to particular urban settings, or forced them to the fringes of country towns. This set up or augmented social barriers which already existed in other forms, and which only a few of them were able to cross. The same was the case in the north. For example, on pastoral stations the Aboriginal camps were spatially separate from the areas in which Europeans resided. On government and mission reserves, the same patterns were visible. People living in such conditions were caught in a trap of increasing—*conspicuously* increasing—poverty and squalor. The only Aborigines who escaped were those who still remained traditionally-oriented.

The problems of housing which in recent years have received so much publicity as a primary symptom of Aboriginal deprivation, were and are only part of this wider syndrome. Lack of communication between Aborigines and other Australians was, and is, perhaps much more significant. The school was for a long time, and still is in many cases, an outstanding example of minimal communication, and of puzzlement on the part of educational authorities as to how to remedy that situation. The remedy, of course, did not lie in tackling only one aspect and leaving the rest in a kind of social vacuum, as was often the case in the

immediate past. The approach had to be—should have been—in terms of the total configuration: but this has only recently been possible, and then only up to a point.

Among other things, the continuing influence of drinking to excess, which over the years of contact has become virtually endemic—or, to put it in another way, has become patterned behaviour linked to particular positive values that were or are regarded by many Aborigines as being desirable and part of an expected way of life—that state of affairs has become, as more opportunities are offered to people of Aboriginal descent, an inhibiting or retarding factor. The "right to drink", which so many of us supported in the 1950's (and probably would still support on the platform of equality), can, in perspective, be viewed as one of the most obvious ingredients in social and moral deterioration. The present situation at Kalgoorlie, at Wiluna, or in Derby, Wyndham, and Alice Springs, for example, underlines that point. Even more disastrous is the situation at Gove in north-eastern Arnhem Land, near the new town of Nhulunbhuy, or at Oenpelli in western Arnhem Land. The solution does not lie in "teaching Aborigines to drink" or in gaoling Aborigines for drunkenness, but in education and rehabilitation. And, of course, it cannot be isolated from the picture of what is happening in the wider Australian scene—the patterns of expected and actual behaviour among Australians in general. This issue has not yet been seriously tackled by State or Commonwealth authorities. It is tempting, at this juncture, to comment on Aborigines and the law. I shall not do so, except to say that legal representation is by no means all that is required. It is true that negative discrimination against Aborigines is apparent in this sphere, even though virtually all prejudicial legislation in this respect has been lifted. The problems involved are not simply within the courts; they are to be found embedded in social situations, the informal, human situations in which people of Aboriginal descent are involved.

Many of the conditions I have mentioned stem at least to some extent from the past: but they have their repercussions in the present, and influence future trends. Changing them in a positive sense means re-programming or re-directing the course of events. And to know what to do in this respect requires, initially, research. This is or should be a significant component in all welfare developmental programmes, but the need for it is being recognized far too slowly. In any re-programming, account must be taken of what can be called "the Aboriginal heritage". Broadly, it has two inter-related facets. One concerns the "*traditional*, specifically Aboriginal heritage". This is relevant in different ways to all Aborigines, whether they remain traditionally-oriented (as some still are) or are to all intents and purposes ordinary Australians (that is, culturally speaking). Secondly, there is the traumatic history of past and near-present contact. Ideas about this are communicable to on-coming generations. I mean,

here, views and feelings related to being an Aboriginal, being defined as an Aboriginal person, by oneself or by others, in a society dominated by non-Aborigines: restrictions on access to potential advantages, restricted opportunities; and discriminatory attitudes and behaviour. In combination, the two facets of the Aboriginal heritage provide a formidable emotional frame against which to measure virtually the total range of experience, from adaptation and acceptance to opposition and rejection.

IV

The break with older, negative policies and attitudes did not really get under way until just after the second world war. The main motivators were not, at first, Aborigines themselves. But these motivators did include anthropologists. The nature of their work, which involved intimate and sustained relationships with Aborigines, placed them in a strategic position. They were, simultaneously, both preservationalists and activists, concerned with recording and understanding socio-cultural life in its traditional perspective as well as under conditions of extreme change; and they were also concerned with the implications of what they observed in relation to human aspirations, human dignity, and human satisfactions.

The first effective and systematic anthropological field research did not take place until the late 1920's and early 1930's. At that time, when Aboriginal opinion was largely inarticulate, anthropologists (and there were only a few of them) served as intermediaries between Aborigines and administrations, as well as missionaries. At that time, they were almost the only people other than Aborigines themselves who had any real knowledge of what was happening in Aboriginal areas and what Aborigines felt about it. I do not, of course, want to underestimate the influence of welfare agencies. What I am saying refers to social-scientific knowledge. Without anthropologists (plus a very few missionaries and others), virtually no information about Aboriginal life in the immediate past would be available today—and not just in reference to traditional life. Without them, our understanding of present-day conditions would be considerably limited. And, as you will realize, the collection of such material has a direct bearing on contemporary ideas about social identity. This aside, anthropologists have influenced administrative policy at all levels. Moreover, they were instrumental in achieving an almost complete reversal of the older, outmoded policies, as well as helping to turn public opinion toward a more positive appreciation of Aborigines and their culture. This is no exaggeration: it is a matter of history, as yet unwritten.

However, this development must be seen in context, and in relation to current socio-cultural trends within the wider Australian society. The first major break-through occurred with the establishment, during the last war, of army settlements in the Northern Territory. There,

Aborigines came into close contact with a variety of different kinds of Australians—and not just administrators and missionaries, station-managers, stockmen, and so on. Conditions on those settlements were in marked contrast to what existed in their "home" areas. A wage economy was introduced, whereas on many pastoral stations at that time no such payments were available. Army settlements provided housing, showers, latrines, beds and other amenities: on the stations, humpies and huts, and "native camps" were the norm, usually relegated to the local creek bed or some such site. Additionally, the local Aborigines were viewed by the owners and managers of many stations as part of the natural environment, which was there for them to exploit.

Movement outside the confines of such stations and other settlements brought growing awareness among Aborigines themselves of barriers blocking social and spatial mobility where they were concerned. This same upsurge of interest was apparent also in the towns and in the cities, where persons of Aboriginal descent were becoming more vocal, and as a result more visible. A movement had begun which increased in momentum, and brought in its train radical policy changes. A number of years were to elapse before the majority of Aborigines felt its impact. However, in contrast to what had been going on before, those changes were very rapid indeed; and eventually, with varying degrees of effectiveness, they succeeded in partially rechannelling the course of events.

It was in this new climate of opinion and unrest that the ideal of assimilation was forged as far as Australia was concerned, although of course it had been suggested before. Its original premise rested on non-discrimination and on equal opportunities within the wider Australian society for all people of Aboriginal descent. It assumed that traditional Aboriginal life would become a thing of the past, and that socio-economic viability could be achieved through some effort on the part of all those involved and through common consensus. However, the history of past contact militated against that ideal, at least for a substantial part of the Aboriginal population. Contrary forces were at work; and social protest, which previously had been regionally confined and easily dissipated, crystallized and took on wider political significance. At the same time, the Aboriginal population explosion became much less localized than it had seemed to be at first. Spatial mobility increased, there was a stepping-up of educational programmes, and, most importantly, the gradual shaping of a new identity. Recognizing that attitudes and aspirations were changing in these directions, the assimilation aim was officially modified in 1965 to permit a greater emphasis to be placed on traditional Aboriginal culture.

From that point in time, there was no turning back. At the administrative level, further far-reaching changes took place—but not without the prodding of social protest (see R. Berndt 1971: 25-43). Social Service benefits for all

Aborigines, and the right to vote and to drink intoxicating liquor, were introduced unevenly among the States. The Pastoral Award, designed to come into effect in the Northern Territory by 1968, had to be moved forward to 1966 because of the Guirindji (Wave Hill) strike. In 1967, as you all know, a Referendum was held which concerned, on one hand, the inclusion of all Aborigines in the Commonwealth Census and, on the other, the assignment of powers to the Commonwealth to enable it to legislate for Aborigines. As it was framed then, in its two ambiguous questions on which the Australian public went to the poll, the implications were not clear; they have become much clearer over the years.

Policy became more realistic and more reflective of what was happening in the various Aboriginal communities themselves. It was also more receptive to the demands of protest. Of these, two outstanding cases of recent years—the Guirindji sequence, and the Gove Land Rights dispute—had the greatest public and political repercussions. The first, in the Wave Hill pastoral area, concerned employment and independence, coupled with land rights. The other, at Gove, in north-eastern Arnhem Land, was more far-reaching in its significance. It was a direct attack on mining exploitation in that area, which was regarded as taking place at the expense of local Aborigines; and in the litigation which followed, the Aborigines confronted the combined opposition of the Nabalco mining complex and the Commonwealth government. The Aborigines sought to establish ownership of “tribal” lands within the context of Australian law. We all know about the negative judgement in this long-drawn-out case. One of the first tasks of the present Federal government was to establish an Aboriginal Land Rights Commission—not to debate the legal question of whether or not land rights should be given, but to determine how they should be given, and to whom (that is, to what groups of Aborigines).

External intervention and stimulus were apparent in both of these instances—in bringing the issues to a head, in sustaining public attention, and in instigating political action. Further, the issues were raised at a particularly opportune time, when the public was receptive, and when the “Aboriginal cause” was considered to be worth taking up. Aborigines had become good politics, and had attained respectability. But this creation of a congenial atmosphere, with its encouraging possibilities for better conditions, had been preceded by a multitude of processions, sit-ins, student involvement and other forms of protest. A lot of hard work in these and other directions had already gone into it, on the part of Aborigines and non-Aborigines. The Canberra “Embassy” was a highlight of this series, which effectively, in its repercussions, dissipated any hard, overt resistance to Aboriginal rights writ large. It was followed by other manifestations, such as the North Adelaide tent and the Western Australian Parliament Stone (which, incidentally, remains unresolved). By this time, the public had “got the message”, and people of

Aboriginal descent had firmed up their aspirations. However, as I have said, many of these protests were taken up or actively encouraged by non-Aborigines—for valid reasons, because Aborigines were, collectively speaking, disadvantaged. They were also taken up for political and other reasons, and this has been quite apparent in a number of instances.

A measure of the importance of Aboriginal affairs today is what could well be called the “bandwagon approach”. A large number of people, drawn from various academic disciplines as well as from the non-professional public, became involved. What most had in common was an ignorance of Aborigines and Aboriginal life, as well as of the problems of change facing these people. It stimulated consultant firms to mount government-sponsored surveys, which meant big money for their personnel.

The truth of the matter was (and is) that many Aborigines were not always in a position to act for themselves, and this was specially the case in northern areas, though much less so in the south. This meant that they were, and often still are, vulnerable and subject to manipulation. That phase is gradually passing, or, rather, is being redirected into different hands. There is always a danger in this respect, for all peoples—but more so when a people like the Aborigines are concerned, a people who are struggling for equal rights and opportunities and for an effective voice in their own affairs.

V

The public was receptive. In one sense, we can speak of the Aborigines being re-discovered by other Australians (see C. Berndt 1969: 16-34). Often what was sought was a highly romantic picture of traditional Aboriginal life, an encapsulation of exotic elements which could be translated and transformed by novelists, poets, artists, musicians, dancers, and so on. But that transformation, when it was made, had little resemblance to the reality of traditional life; and they used it, not so much to understand it, as to provide an extra dimension to their own work.

Counterbalancing this trend were the hard-core anthropological and social scientific studies which were reasonably objective and had an entirely different aim. Research meant learning for a purpose, not just idle curiosity, and not solely for academic ends. In this way, anthropologists not only provided a detailed record of living traditional life, but explored all aspects of change wherever persons of Aboriginal descent were to be found—in the bush or in the city, to note only two contrasts. What they learned could be applied in relation to Aboriginal advancement. This research was appreciably stimulated by the establishment in 1961 of the Australian Institute of Aboriginal Studies, which sponsors a wide range of research. Then came the Commonwealth Department of Aboriginal Affairs (as it is now called), which is specifically concerned with welfare-oriented research. Additionally, there are the universities, and the

State departments of Aboriginal welfare and planning.

It is within this frame of research that, increasingly, contemporary social issues are being reviewed. There is no need for me to emphasize the significance of all this, except to repeat, what I seem to have said so often: that we cannot afford to neglect learning more about the society in which we live, and becoming better informed about the various forces that are at work within it. A "commonsense" approach based on one's own experience is inadequate: it can lead, as it has done in the past, to more difficulties. And, as part of this broader scene, though only one part of it, an anthropological and social scientific approach to the understanding of problems facing persons of Aboriginal descent is essential if we seek their ultimate well-being.

If other Australians have re-discovered the Aborigines, people of Aboriginal descent are now engaged in the process of re-discovering themselves.

This is not so much the case among traditionally-oriented Aborigines, especially now that policy changes have provided them with an opportunity to sustain and maintain substantial areas of their own culture. The extent to which this will be possible is another matter, and it seems to be a highly selective business—particularly when it is supported by, for example, the Australian Council for the Arts through its Advisory Committee on the Aboriginal Arts; or by official emphasis on being taught in and through their own vernacular languages, with only hazy ideas about the kind of content that this could entail as far as their traditional culture is concerned. How much of that culture can survive, and for what functional reasons, is a subject I shall not go into here—although it is crucial to this particular issue. Opportunities do exist: but it is also true to say that what will survive will be radically different from what it was in the purely Aboriginal situation—and what there was before cannot be artificially resuscitated.

The process of people of Aboriginal descent re-discovering themselves, is something else again. Out of a long history of dependence and subordination, paternalism and protection, maltreatment and neglect, and even worse—out of all of that and more, has arisen a resentment which has become increasingly pronounced. This has resulted, as I have said, in protest—some of it mild, some of it aggressive. And it is within this context that the new image of Aboriginality is being formed. This has been projected on to the wider Australian community in two ways.

One takes the form of demands that people of Aboriginal descent should be able to make decisions for themselves about their own affairs, and the corollary (insisted on by some of them) that nobody else should be allowed to do so. This has stimulated the emergence of Aboriginal spokesmen and leaders on the State and national levels. In this respect, the southern urbanized people of Aboriginal descent have had a considerable influence. The other, related to the

first, is manifested in a concern for cultural preservation and Aboriginal revival. A wave of feeling for "Aboriginal" identity—which could eventually lead to pan-Aboriginality—seeks to establish a common socio-cultural heritage. It is the "idea" of traditional Aboriginal life which is used for this purpose—and not the reality of what was once traditional semi-nomadic existence. This has been expressed through highlighting Aboriginal religious features, especially in regard to secret-sacred material and sacred sites, "law-carriers" or "elders" and male authority in the ritual sphere. With this has come, or has been more clearly stated, justification for land ownership, and not necessarily in economic terms, but in terms of the spiritual and emotional linkages which were pivotal features of traditional life. It is, in fact, a pseudo-renaissance.

It is important not to underestimate the significance of the movement toward Aboriginal identity, because this is used to define persons of Aboriginal descent in contrast to non-Aborigines. It may also be framed in terms of "moderates" *versus* "extremists"—Black Theatre as a medium of protest, *versus* Black Power; or, put simply, "Black" *versus* "White". Views are hardening, as one might expect them to do—always bearing in mind the history of Aboriginal emergence as a political force in Australian society. That identity, whatever its outward manifestation, has political implications; and Aborigines are well aware of these, as is the current Federal government. Within that picture is Aboriginal identity as a positive expression of a pride in being Aboriginal and in having a common background, however far that may be removed from the actualities of the past. That identity must be seen in a dual sense, as having something to do with the traditional past and also something to do with the struggle for equality, against what appeared at times to be insurmountable odds. Such an identity can help to provide emotional security and a sense of belonging which, outside the traditional Aboriginal scene, has been sadly lacking. This is probably one of the most significant developments that have taken place over the years—much more important, in my view, than the upsurge of political awareness which, however, can be viewed as part of it.

Contrasts between "Black" and "White" are becoming increasingly irrelevant and outmoded in this present-day world, in spite of numerous examples to the contrary. Such catchwords point to supposed physical characteristics and say little about mental ability and cultural attainment. Further, they point to political discrimination and to prejudice from either side of the ethnic fence. Such contrasts are not anthropologically sound, and they never were. As far as the Australian Aborigines are concerned, they are not "black", even the darkest of them in the northern coastal regions. What does make good sense, anthropologically, is cultural diversity and the sustaining of particular heritages.

The "new" Aborigines—and I use that term generally to refer to all those persons who are

of Aboriginal descent or who identify themselves in that way—the new Aborigines are in a position, and have not hesitated, to carve out for themselves a particular niche in Australian society, and in the process to develop an identity which should, ideally, symbolize two features: (1) a distinctive contribution to Australian society generally and (2) a particular way of tackling their own problems and their own projects. By this last, I mean that so many projects which are being set up today are stimulated from the “outside”, and their organization and motivations are in fact non-Aboriginal. Their aim is to achieve socio-economic viability in both short and long range terms. But just because these may be run or operated by persons of Aboriginal descent, that does not automatically make them “Aboriginal”. They must also be fitted into a particular ethos, into a particular framework of ideas which could be defined as Aboriginal. Aboriginal identity, and what is meant by that label, could provide that ethos.

It is within this context, as in others, that research—especially anthropological research—becomes vitally significant. As far as Aborigines are concerned, systematic research is needed into all aspects of Aboriginal life: traditional, and in terms of current and past changes, and in relation to all conditions of living wherever these are to be found. It is necessary to have a detailed understanding of a large range of social situations, so that that knowledge can be applied practically. I am not, here, emphasizing its significance in purely professional terms: that is another matter. I am concerned, though, that the results of such work should be available to all who are involved in Aboriginal advancement, including Aborigines themselves. For one thing, a meaningful framework for social identity can be sustained only through such knowledge.

Various administrative policies and their translation into action must rest on a firm basis of understanding what is being done and what can result from it. Too often, in my experience, such research has been ignored, or hasty surveys by commercially-oriented research consultants have been made and ventures initiated with little or no awareness of what the possible implications might be for the people themselves. The States and the Commonwealth have both erred in this respect. Human beings are too valuable a commodity to be treated so brusquely. It is not money alone which will transform the Aboriginal scene. Rather, that hinges on how money is spent; and how it is spent should rest

on systematic research, with proper attention to the needs and wishes of the people involved. They require personal attention, and local situations require local consideration. In regard to the last, centralization in respect to Canberra or elsewhere, almost inevitably overshadows local perspectives. It can spell impersonalization. It also means that more controls are likely to be imposed—together with more stress on uniformity and less on diversity, which (within a certain range) is a necessary aspect of ordinary living. Anthropologically, cultural diversity has almost an intrinsic value of its own, as something which is of immense importance to mankind, just as are individual variations. In relation to people, centralization could mean less, or less effective, management in their own affairs.

This point is quite vital. Aborigines are only now being really involved in processes of decision-making. Only now are alternative choices available to them. There are different ways of achieving similar goals; and those different ways, or the choices relevant to them, should be kept open. Moreover, a reasonable choice from among a range of possible alternatives can be made only if the persons involved are aware of the consequences. One of the major tasks of the social sciences is to supply that information in a form which can be used by people who do not have particular training in that direction. It is the responsibility of all Aboriginal administrative agencies to seek out that knowledge and to apply it. And it is to the advantage of all Aborigines to be able to draw on such knowledge. Hopefully, also, more Aborigines will come to have a greater appreciation of social science research, in its theoretical as well as its applied aspects, and some of them will themselves carry out such research, not only among their own people but in the wider Australian scene and beyond.

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2.—Clastic dykes at Albany, Western Australia

by John G. Kay¹

Manuscript received 22 August 1972; accepted 20 February, 1973.

Abstract.

Four clastic dykes outcrop on the northern shore of the entrance channel of Princess Royal Harbour, Albany. The largest dyke is about 1 metre wide, the others less than 10 cm wide. All are made up of well lithified, quartz-rich, wacke-type sediment and are enclosed by biotitic granitic gneiss.

Introduction

Clastic dykes have been observed at several widely scattered localities in Western Australia, for example at Watheroo, the Billeranga Hills, Puntapin Hill, Dillon Bay and Albany. Of the known examples, only those at Watheroo have been described (Logan 1958). The purpose of this paper is to record the occurrence at Albany.

Description of dykes

The clastic dykes at Albany outcrop on the northern shore of the entrance channel of Princess Royal Harbour, as shown in Figure 1. Access is by bitumen road from the Albany townsite. The dykes cut across a flat gneissic pavement which is about 10 metres wide, and continue northward beneath unconsolidated sand and southward under the harbour waters; it is, therefore, not possible to see their full length. These dykes trend approximately 300°, almost at right angles to the shore line, and dip 80° to 85° W. A third dyke extends south-

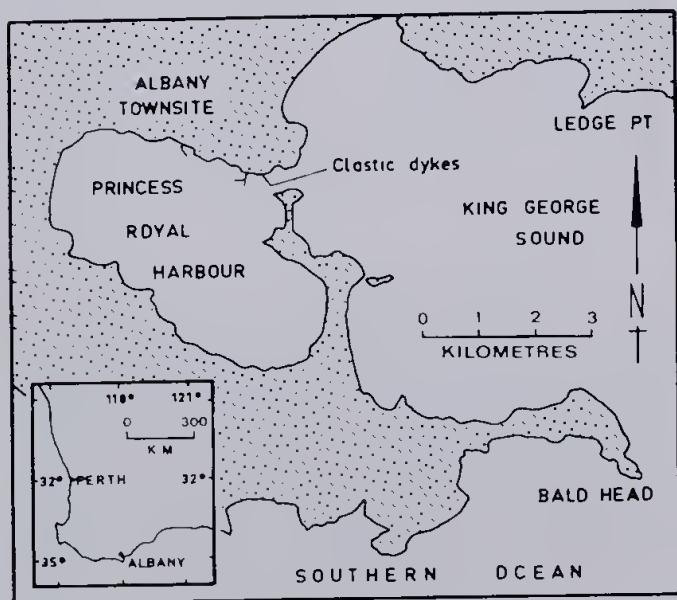


Figure 1.—Locality map.



Figure 2.—General view looking south along the strike of the largest dyke. This dyke is about 1 metre wide.

ward from the shore line and at very low tide its northern few metres are exposed. A fourth dyke occurs on a small, rather rough gneissic headland immediately east of the pavement. The widest dyke is about 1 metre in width and is shown in Figure 2; the others are narrower, averaging less than 10 cm in width. They are well lithified and are as resistant to marine erosion as the adjacent gneiss.

The dykes simulate normal intrusives, and their clastic lithology is not obvious unless looked at closely. Included fragments of gneiss have the appearance of xenoliths. Margins, particularly those of the widest dyke, are possibly offset, but foliation patterns in the

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gneissic country rock are not sufficiently distinctive to allow indisputable matching. The dykes are enclosed by biotitic granitic gneiss which has a foliation trending 250° and dipping 65° N. Numerous joints cut the dykes in a diagonal pattern and many continue without refraction across the dyke boundaries into surrounding gneiss.

The dykes are made up of well-lithified, quartz-rich wacke-type sediment. Detrital particles include quartz, quartzite, microcline, plagioclase, pinitized cordierite, zircon, apatite and rare fragments of gneiss; quartz grains make up approximately 70 per cent. Size sorting is very poor, and grains range from less than 0.05 mm to more than 4 mm across. Roundness and sphericity are also variable, and all gradations from well-rounded, sub-spherical grains to sharply angular fragments are present. The boundaries of many grains are irregular and embayed as a result of marginal solution and matrix encroachment.

Between 5 and 15 per cent of the rock is made up of matrix, originally clay, but now chlorite, biotite, muscovite and limonite. Matrix in the narrow dykes is mostly fine-grained dark green chlorite, with rare flakes of muscovite and biotite, whereas in the widest dyke it is limonite and muscovite. This difference is expressed in the greyish green colour of the narrow dykes and the

dark purplish brown of the widest dyke. Seemingly, the original clay matrix was altered to chlorite, which in turn partly altered to biotite and muscovite in the narrow dykes and almost completely altered to muscovite and limonite in the widest dyke. The alterations are probably authigenic, but the possibility of slight metamorphism cannot be excluded. Reasons for the matrix differences are unknown. Secondary muscovite flakes range in size up to 0.05 mm in thickness and more than 0.8 mm across, and commonly are moulded around detrital grains. Penetration into detrital grains is rare. The lithification and secondary mica development suggest that the clastic dykes are not recent, and may be of considerable age. Sediments comparable with the dykes are not known elsewhere in the Albany area.

Specimens of the Princess Royal Harbour clastic dykes are housed in the rock collection of the Department of Geology, The University of Western Australia; the largest dyke is represented by specimens 44933 and 48211, the smaller dykes by specimens 44934 and 48210.

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3.—The pouch of *Planigale subtilissima* and other dasyurid marsupials

by P. Woolley¹

Manuscript received 22 May 1973; accepted 17 July 1973

Abstract

Planigale subtilissima is little known. In the two female specimens available for study the structure of the pouch was different from that of all other dasyurid marsupials for which information is available. The structure of the pouch is described and compared with that of other dasyurids. Information obtained at the time of capture of the animals suggests that *P. subtilissima* breeds in the summer months.

Introduction

Two female *Planigale subtilissima* collected by the Combined Museum's Expedition to the Ord River, Western Australia in mid-January, 1972 were maintained at the Western Australian Museum, Perth by M. Archer until mid-September and then at La Trobe University, Melbourne by the author until their deaths in November, 1972. When captured one female (number 1) had young on the nipples but there were no young in the pouch of the other female (number 2). Both females were sent to Perth soon after capture; the young of female 1 were lost in transit.

Previously this species was known only from the type specimen,* a male, caught by Dr. Mjöberg's Swedish Scientific Expedition to Australia 1910-13 (Lonnberg 1913) and from six animals obtained by B. Rudeforth, in December 1949. Four of these animals, including both sexes, were maintained alive in the Zoology Department of the University of Western Australia, and general observations on their biology were made. Over a four month period in captivity "no young were observed, although the pouch of the female seemed to change in size as though in preparation for carrying young during that time" (Rudeforth 1950).

The pouch of *Planigale subtilissima*

On arrival in Perth the pouch of ♀1, which was now empty, was stained, the nipples elongated and the pouch hairs long and stained (M. Archer *in litt.*). The appearance of the pouch of ♀2 suggested to Archer that this female also was in breeding condition. The pouch hairs were slightly stained and slightly longer than the surrounding body hair and the nipples were well developed. By 10th February

the pouch hairs had doubled in length. However, no young appeared and within a month the pouch hairs had become less prominent and remained so.

When the animals arrived in Melbourne the pouch of each animal was inconspicuous and the entrance to it partly covered by long hairs. Because of the difficulty in handling these very small animals (body weight 5.0 to 6.0 g) no detailed examination of the pouch was attempted while the animals were alive. The superficial appearance of the pouch throughout the period the animals were alive in Melbourne can be seen in Figure 1.

Examination of the pouch following the death of each animal revealed a structure different from that recorded for any other species of dasyurid marsupial. When the hairs covering the pouch region were clipped a fold of skin forming an anteriorly directed pouch with the opening at the rear could be seen, but no nipples could be found on the abdominal skin beneath the overlying fold. The pouch skin was dissected away from the body and two pockets were seen projecting forward from the anterior margin of the skin fold (Figure 2). After everting the pockets 5 nipples could be seen around the antero-lateral margins of each pocket (Figure 3). In each animal the hairs in the pockets and on the skin lining the entrance area were reddish brown in colour and there was an accumulation of dry red secretion around them.

The pouch of other dasyurid marsupials

The pouches of other species of dasyurid marsupials for which information is available appear to be of three general types:—

Type 1. The mammary area has no covering fold of skin. Marginal (usually lateral) ridges of skin develop during the breeding season.

Type 2. The mammary area is partially covered by a crescentic antero-lateral fold of skin. The fold is usually deepest anteriorly.

Type 3. The mammary area is covered by a circular fold of skin.

These three types of pouch are shown diagrammatically in Figure 4, together with a diagram of the pouch of *P. subtilissima* (Type 4) for comparison. The type of pouch found in various species of dasyurid marsupials is listed in Table 1.

The typical pouch condition may not always be apparent; it is seen only in the breeding season in all species with a Type 1 pouch, and

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* *Phascogale subtilissima*, transferred to *Planigale* by Troughton (1928).



Figure 1.—Ventral view of female 1 showing the entrance to the pouch which is partly covered by long hairs.

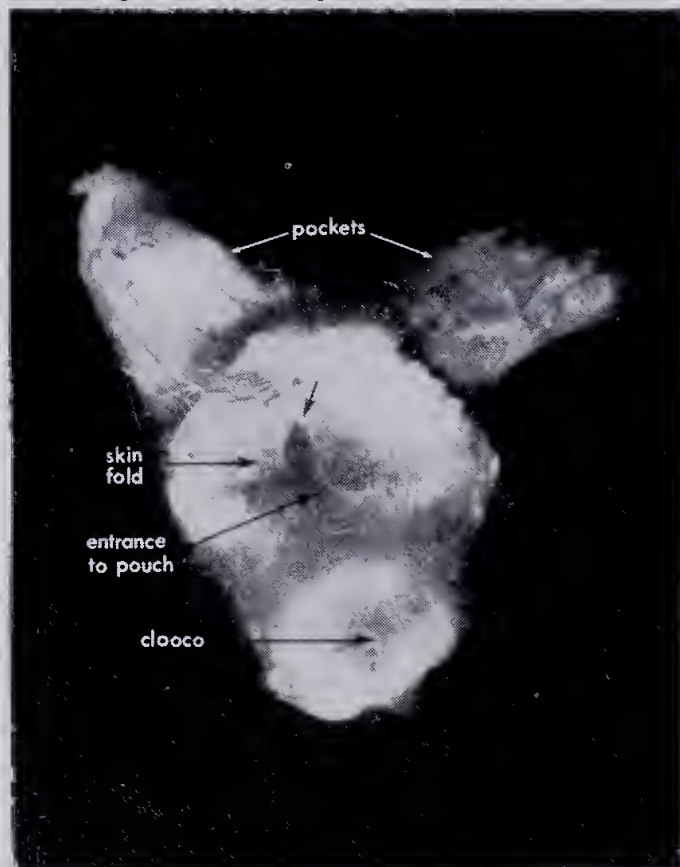


Figure 2.—The pouch and cloacal region of female 2 dissected from the abdomen. The V-shaped indentation (arrowed) in the skin fold covering the entrance to the pouch was probably an artefact caused by contraction of the loose skin. It was not present in female 1.



Figure 3.—The pouch and cloacal region of female 1 dissected from the abdomen. The skin fold has been turned forward and over and the two pockets everted to show the interior of the pouch. Arrows point to two of the five nipples in the left pocket.

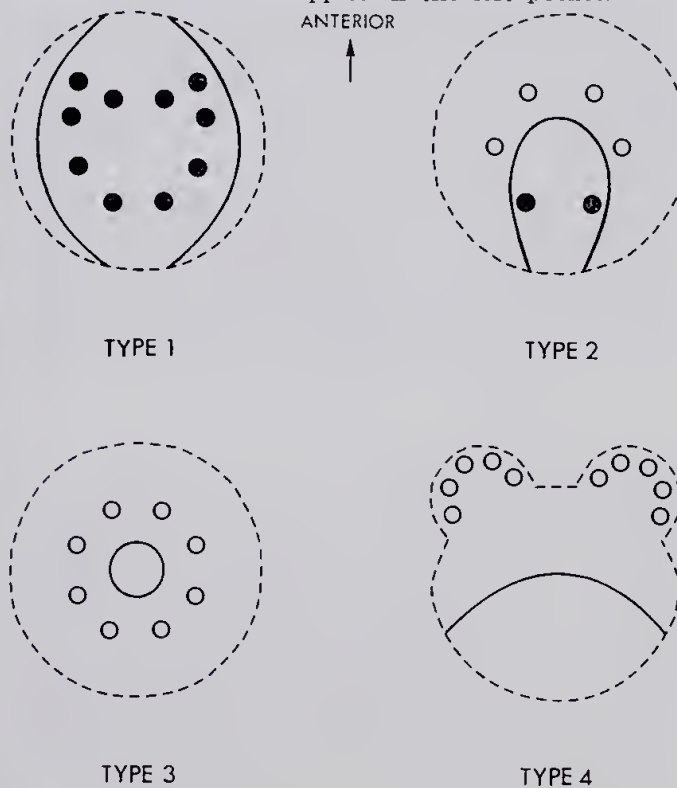


Figure 4.—Diagrammatic representation of the types of pouch found in dasyurid marsupials. The broken lines indicate the limits of the pouch area. The solid lines indicate, in Type 1, the marginal ridges of skin, and in Types 2, 3 and 4, the free edge of the fold of skin at the entrance to the pouch. Where the nipples are exposed they are shown as solid rather than open circles.

Table 1

The type of pouch in various species of dasyurid marsupials

Species	Pouch Type	Described by
<i>Planigale subtilissima</i>	4	Woolley, this paper.
<i>Planigale ingrami</i>	2	Troughton (1928), Heinsohn (1970).
<i>Planigale tenuirostris</i>	2	Troughton (1928).
<i>Planigale gilesi</i>	2	Aitken (1972).
<i>Antechinus maculatus</i>	2	Pocock (1926)—as <i>Phascogale minutissima</i> , Johnson (1964).
<i>Antechinus stuartii</i>	1	Pocock (1926)—as <i>Phascogale unicolor</i> , Horner and Taylor (1959) and Marlow (1961) under misnomer <i>A. flavipes</i> , Woolley (1966a, b).
<i>Antechinus flavipes flavipes</i>	1	Pocock (1926)—as <i>Phascogale flavipes</i> , Fleay (1949), Woolley (1966b), Wakefield and Warneke (1967).
<i>Antechinus flavipes leucogaster</i>	1	Woolley (1966b).
<i>Antechinus godmani</i>	1	Wakefield and Warneke (1967).
<i>Antechinus apicalis</i>	1	Woolley (1971a).
<i>Antechinus rosamondae</i>	1	Ride (1964).
<i>Antechinus macdonnellensis</i>	1	Spencer (1896), Woolley (pers. obs.)
<i>Antechinus swainsonii</i>	1	Pocock (1926)—as <i>Phascogale swainsonii</i> , Fleay (1932), Wakefield and Warneke (1963), Woolley (pers. obs.).
<i>Antechinus minimus</i>	1	Wakefield and Warneke (1963).
<i>Antechinomys spenceri</i>	2	Pocock (1926), Woolley (pers. obs.).
<i>Antechinomys luniger</i>	2	Lidicker and Marlow (1970).
<i>Sminthopsis crassicaudata</i>	3	Pocock (1926), Fleay (1929), Smith and Godfrey (1970), Woolley (pers. obs.).
<i>Sminthopsis larapinta</i>	3	Godfrey (1969), Woolley (pers. obs.).
<i>Dasyurus cristicauda</i>	1	Spencer (1896), Pocock (1926), Jones (1949), Fleay (1961), Michener (1969), Woolley (1971b).
<i>Dasyuroides byrnei</i>	1	Spencer (1896), Jones (1923), Pocock (1926), Woolley (1971b).
<i>Phascogale tapoatufa</i>	1	Fleay (1934).
<i>Satanellus hallucatus</i>	1	Pocock (1926)—as <i>Dasyurus hallucatus</i> , Fleay (1962), Johnson (1964).
<i>Dasyurus viverrinus</i>	1	Pocock (1926), O'Donoghue (1911), Hill and O'Donoghue (1913), Fleay (1935a), Green (1967).
<i>Dasyurus geoffroii</i>	1	Pocock (1926).
<i>Dasyurus maculatus</i>	2	Pocock (1926), Fleay (1940).
<i>Sarcophilus harrisii</i>	2	Pocock (1926), Fleay (1935b), Green (1967), Guiler (1970).
<i>Thylacinus cynocephalus</i>	2	Pocock (1926).
<i>Myrmecobius fasciatus</i>	1	Jones (1923), Calaby (1960).
<i>Neophascogale lorentzii</i>	2	Pocock (1926)—as <i>Phascogale lorentzii</i> .
<i>Phascocolosorex dorsalis</i>	2	Pocock (1926)—as <i>Phascogale dorsalis</i> .
<i>Myoictis melas</i>	1	Pocock (1926)—as <i>Phascogale thorbeckiana</i> .

it may not be present in immature females of species with another type of pouch e.g. *Antechinomys spenceri* (Type 2 pouch). The skin fold in this species does not develop until the approach of the first breeding season (Woolley, pers. obs.) and this may account for statements that a pouch is absent in *A. spenceri* (see Lidicker and Marlow 1970 p. 219).

The appearance of the pouch is known to change during oestrus, pregnancy and lactation. The changes that occur during oestrus and pregnancy have been described in detail for *Antechinus stuartii* (Type 1 pouch) by Woolley (1966a, b), for *Dasyurus viverrinus* (Type 1 pouch) by O'Donoghue (1911) and for *Sminthopsis larapinta* (Type 3 pouch) by Godfrey (1969). Other species with a Type 1 pouch in which changes similar to those observed in *A. stuartii* during pregnancy, but not during oestrus, have been recorded include *Antechinus flavipes flavipes* and *Antechinus flavipes leucogaster* (Woolley 1966b), *Antechinus apicalis* (Woolley 1971a), *Dasyurus cristicauda* (Michener 1969; and Woolley 1971b) and *Dasyuroides byrnei* (Woolley 1971b). Smith and Godfrey (1970) noted changes in the pouch of pregnant *Sminthopsis crassicaudata* (Type 3 pouch) similar to those seen in *Sminthopsis larapinta*. Identical changes in the pouch are known to occur in females of many of these species kept isolated from males during the breeding season. Among species with a Type 2 pouch, changes in the pouch during the breeding season have been observed in *Planigale ingrami* (Fleay 1965), *Antechinomys spenceri* (Woolley, pers. obs.), *Dasyurus maculatus* (Fleay 1940) and *Sarcophilus harrisii* (Fleay 1935b).

The changes in the pouch that occur during lactation involve mainly enlargement of the mammary area, nipples and skin folds. Staining of the pouch skin and hairs may also occur. When the young are weaned the pouch slowly regresses to approximately the condition seen immediately prior to the commencement of the breeding season, except that the nipples remain slightly elongated and the pouch hairs sometimes lightly stained. The appearance of the nipples and pouch hairs provide a means of distinguishing between females that have reared young and those that have not.

Discussion

The pouch of *P. subtilissima* differs from that of other dasyurid marsupials in that the mammary area is more fully enclosed. The nipples are not located on the abdominal skin beneath the skin fold as in species with an enclosed mammary area (Type 2 or Type 3 pouch), but in two anteriorly directed pockets which are extensions of the area covered by the skin fold. Archer was able to see the nipples in both females when he received them but at the time of their deaths the nipples could not be seen until the pockets were everted. This suggests that the proportions of the pouch of each

animal were different at these times. Female 1 was known to have been suckling young and the nipples may have been visible as a result of general enlargement of the pouch to accommodate the young. The fact that he could see well developed nipples in female 2, together with the similarity in the appearance of the pouches of the two females, suggests that female 2 also had been suckling young which may have been lost at or shortly before capture. These observations on pouch development in the two females, together with that of Rudeforth (1950) mentioned above, suggest that *P. subtilissima* breeds in the summer months, unlike the majority of dasyurid marsupials (Woolley 1973).

A long period of lactation, ranging from 10 weeks in some species to 5 months or more in others (Woolley 1973) is characteristic of dasyurid marsupials. Like most other marsupials the young are born at a very early stage of development by comparison with placental mammals. The young suckle continuously for some weeks and then intermittently for the remainder of the period of lactation. When suckling becomes intermittent the young are not carried about by the mother at all times. During the period when suckling is continuous and the young are carried at all times the amount of cover afforded the young by the pouch is different for each type of pouch. In those species with a Type 1 pouch the young are almost completely exposed from the time of birth. The young of species with a Type 2 pouch may be covered by the skin fold only during the very early part of the period when suckling is continuous, as in *Antechinomys spenceri* (Woolley, pers. obs.) or for the entire period, as in *Sarcophilus harrisi* (Fleay 1935b). Fleay records that in this species suckling is continuous for 15 weeks, and 4 young can still be carried completely inside the pouch at 15 weeks. The young of *Sminthopsis larapinta*, which has a Type 3 pouch, are fully enclosed within the pouch for about 37 of the 40 days during which suckling is continuous (Godfrey 1969). Similarly, in *Sminthopsis crassicaudata*, which also has a Type 3 pouch, the young are fully enclosed while suckling is continuous (Ewer 1968). While no information is available on the development of the young or the duration of lactation in *P. subtilissima* it seems likely that the more fully enclosed mammary area would provide complete cover for the young for some time during lactation. The different types of pouch found in dasyurid marsupials must provide different environments for the young, at least during the early part of lactation, but what effect this may have on the development of physiological processes in the young is not known.

No obvious correlation can be seen between the type of pouch found in different species and the habitat of the animals, body size, the number of young per litter and the duration of the period of continuous suckling or the total period of lactation.

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4.—Cainozoic stratigraphy in the Perth area¹

by Patrick G. Quilty²

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Abstract

The Cainozoic sequence in the vicinity of Perth is described. The two major sedimentary cycles recognised are Late Palaeocene-Early Eocene and Early-Middle Miocene. The former includes the Kings Park Formation (including the Mullaloo Sandstone Member, defined herein). The later cycle includes the Stark Bay Formation, also defined herein, and possibly an overlying poorly-known carbonate unit. The Mullaloo Sandstone Member is interpreted as a marine-deposited sand from the early Swan River, and the rest of the Kings Park Formation as a more southerly estuarine to marine unit. The Stark Bay Formation is a carbonate-chert formation deposited on the inner continental shelf. Age and ecological results are based on planktonic and benthonic foraminifera. *Lepidocyclina* aff. *howchini* Chapman and Crespin is recorded from Gage Roads No. 2. It indicates that there were warm waters in the Early Miocene all around the Australian coast and also that the warm water planktonic foraminiferal zonation may be used in the Miocene of the Perth Basin.

A fairly widespread Pliocene-Quaternary marine incursion is represented in the area by thin, discontinuous sediments with characteristic molluscan faunas.

Introduction

History of study

Several published papers have been concerned with the Tertiary palaeontology of the Perth Basin, mainly involving the Kings Park Formation onshore in the vicinity of Perth. Several unpublished results are also worthy of recognition. Recently, there has been an upsurge in interest in the younger Cainozoic and several preliminary papers have appeared. Tertiary sediments are not known from outcrop in the area under review, all evidence presented here having been gleaned from bore material.

The earliest work in the area was reviewed by Coleman (1952) and that will not be repeated here. The major palaeontological results are contained in papers by Parr (1938), Coleman (1952), Cookson and Eisenack (1961), and McGowran (1964). Relevant unpublished works are those by Pudovskis (1962) and Cockbain and Ingram (1967). Wells (1943) made a brief comment on a coral fauna and Glaessner (1956) described a crustacean from one of the bores.

Parr's (1938) paper was the first major contribution to the understanding of age relationships in the area. He examined in detail the foraminiferal fauna from the Kings Park No. 2 Bore and assigned an Eocene age by comparison with contemporary American studies, mainly by Cushman. This Eocene age was accepted for quite some time, although some aspects of the fauna were confusing.

Coleman (1952) examined more material from a total of six bores in the Perth metropolitan area. His paper carried two important footnotes. One foreshadowed the application of the name Kings Park Shale for the sequence studied. The other hinted at a possible Palaeocene age by comparison with contemporary studies in Sweden. Coleman recorded a more diverse foraminiferal fauna and several more groups of fossils than did Parr. He noted difficulties in biostratigraphic correlation in the Perth metropolitan area bores.

Cookson and Eisenack (1961) expanded the area of interest to the Rottnest Island Bore. Two samples from the Kings Park Formation interval were described as younger than Victorian time equivalents of the Kings Park Formation in its type section.

Pudovskis (1962), while still accepting the Late Eocene age for the Kings Park Formation, produced what is still the most detailed lithological correlation of wells in the area. His report used information from 38 wells spread from Pt. Peron and Rottnest Island in the west to the Midland Railway workshops and Helena Vale in the east.

McGowran (1964) restudied Parr's samples and concluded that the age of the Kings Park Formation in its type section (Kings Park No. 2) is Late Palaeocene, *Globorotalia pseudomenardii* Subzone of the *G. velascoensis* Zone of Berggren (1965) (*G. pseudomenardii* Zone of Bolli, 1957). This is the same as zone P4 in the comprehensive scheme of Blow (1969) as detailed by several authors including Berggren (1971). McGowran suggested that it was unlikely that the material in the Rottnest Island Bore (284-666 m) would be younger than that in Kings Park No. 2.

Cockbain and Ingram (1967) examined foraminifera and palynomorphs from the Rottnest Island Bore and recorded a Late Palaeocene to Early Eocene age for the sediments there.

No foraminiferal investigations have been made on bore material from the post-Miocene in the Perth area. However, Mr. G. W. Kendrick, W. A. Museum, has commenced detailed studies of molluscs (mainly bivalves) from shallow bores and from outcrops of the Coastal Limestone (Darragh and Kendrick, 1971; Kendrick, 1960). Enough information is available from his work to suggest that there are at least two post-Miocene episodes of marine sedimentation in the Perth area.

Scope of this investigation

All wells drilled offshore in the Perth Basin have been drilled for West Australian Petroleum Pty. Limited (WAPET). Study of the bores drilled to-date permits this summary to be made.

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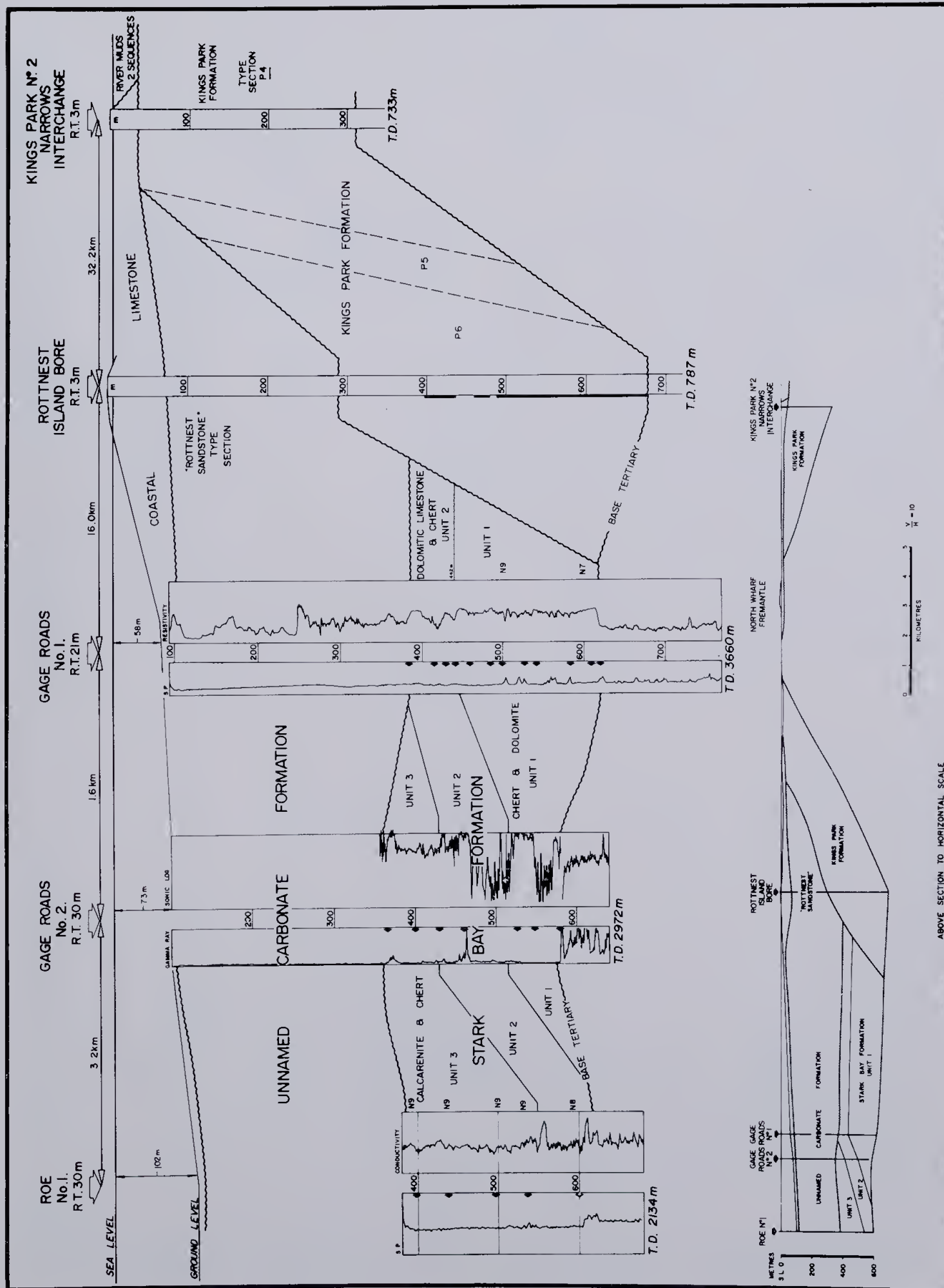


Figure 1.—Tertiary section Kings Park No. 2-Rce No. 1.

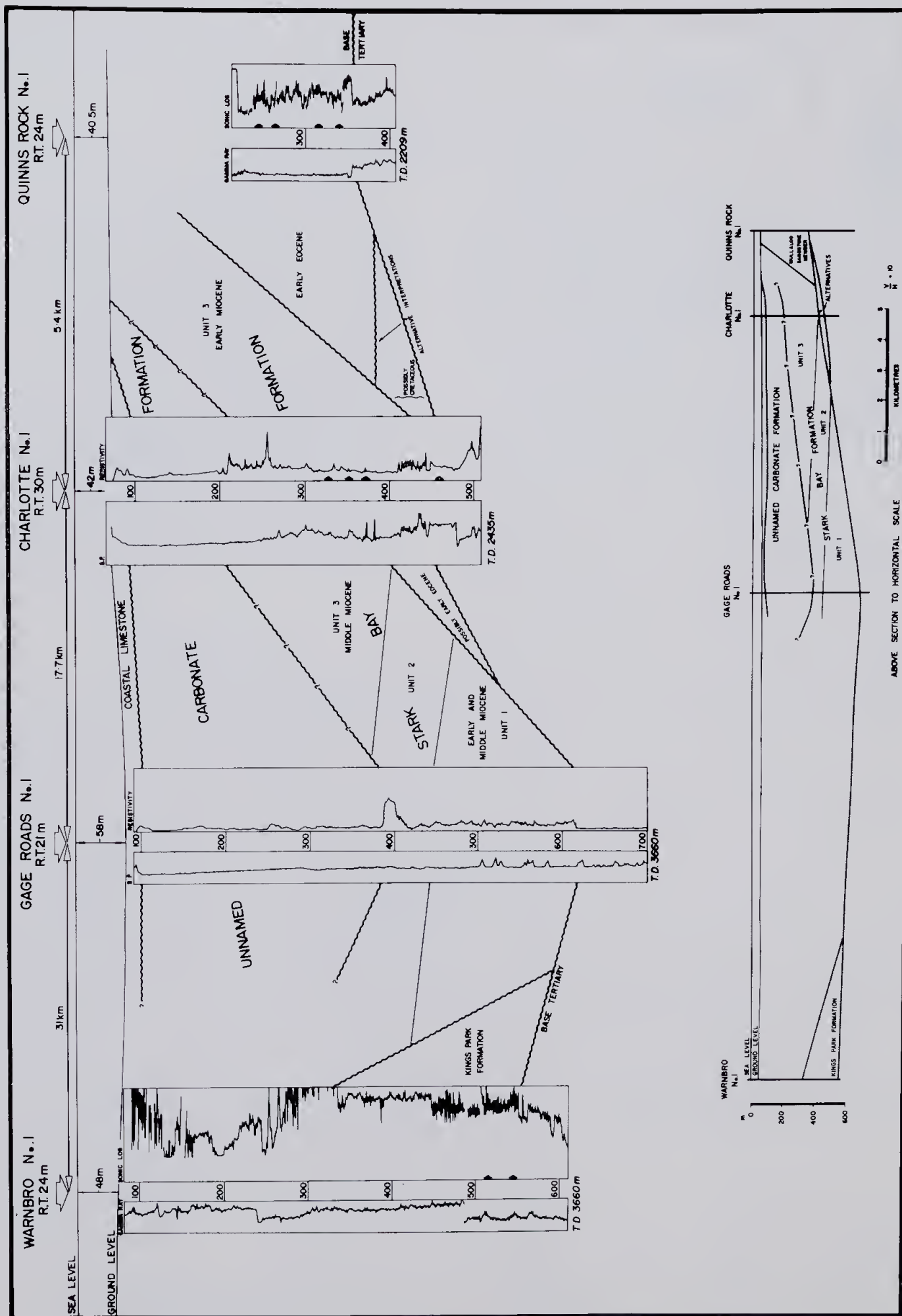


Figure 2.—Tertiary section Quinns Rocks No. 1-Warnbro No. 1.

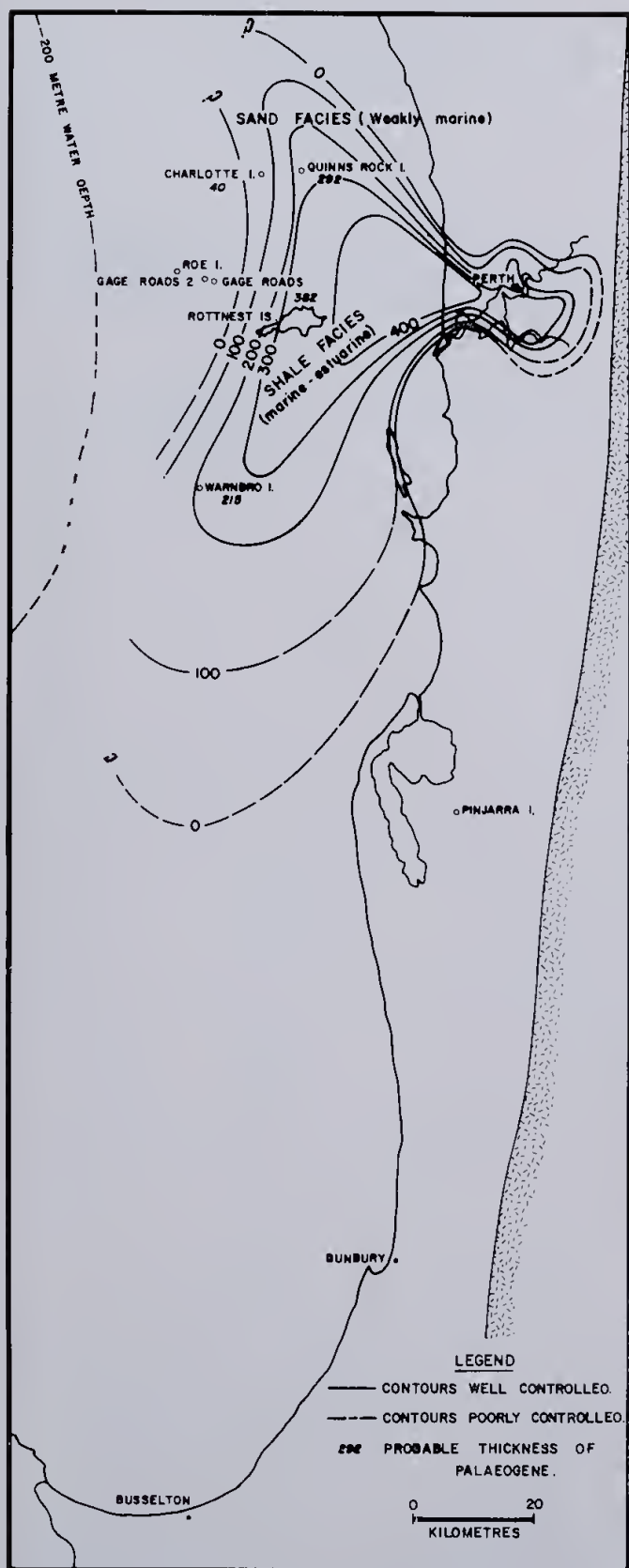


Figure 3.—Isopach and palaeogeographic map of the Kings Park Formation.

There is a large area of Tertiary, between the sequence in the Carnarvon Basin 1000 km to the north and in the Plantagenet Group, 400 km to the south from which little has been studied. Apart from the Kings Park Formation,

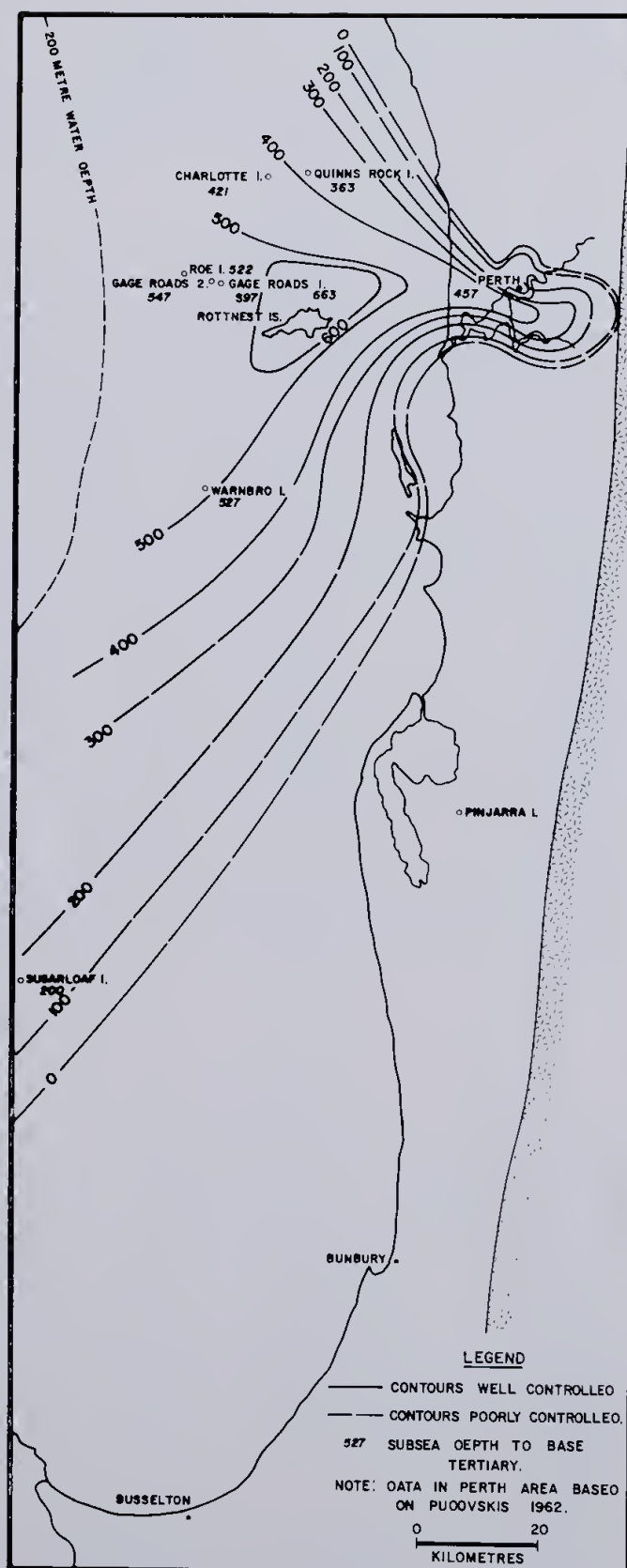


Figure 4.—Tertiary isopach and depth to base Tertiary.

no proven Tertiary marine faunas or lithological units have been defined yet from the Perth area.

This report deals mainly with the Palaeocene, Eocene and Miocene, but the younger sediments are noted briefly for completeness. Character-

istic foraminifera are illustrated on two plates. Figures 1 and 2 are compilations of the information detailed in the major part of this paper. Figures 3 to 5 show the palaeogeography and distribution of the units mentioned. Figures 6 and 7 give electric log and lithology of the new units defined and Figure 8 is a summary of the Cainozoic stratigraphy of the Perth area.

Sample reliability

The most reliable samples are from conventional cores (C) or sidewall cores (SWC). These are taken from the depth indicated. All available samples were used in this study.

In many cases, the only samples available are from ditch cuttings (DC). These samples are circulated to the surface in drilling mud and removed from the mud on vibrating screens. While they are usually fairly representative of the fauna at the depth taken, they may contain much downhole contamination, or rarely, may be entirely composed of contaminants. Ditch cuttings samples are of a much lower order of reliability than core samples.

Depth Measurements.—Throughout this work, depths mentioned are drill depths; this is, depths below the Rotary Table (R.T.). All measurements were originally recorded in feet, and have been converted to the nearest metre.

Repositories.—Rock specimens are held at the Geological Survey of Western Australia and at the Bureau of Mineral Resources, Geology and Geophysics, Canberra. The foraminifera figured on the plates are housed in the Palaeontological collection of the Geology Department, University of Western Australia and the number following the initials U.W.A.G.D. is the catalogue number in that collection.

Discussion of the sections examined

Kings Park area

No new material has been examined from the type section of the Kings Park Formation, as the age, fauna and lithology have been described adequately by Parr (1938), Coleman (1952) and McGowran (1964).

The Kings Park Shale was described in McWhae *et al.* (1958, p. 130) as consisting of "grey calcareous shales and claystones . . .". Pudovskis (1962) stated that it "consists predominantly of grey calcareous, glauconitic siltstones, shales and some sandstones. Some thin hard limestone beds are present in the lower part of the formation". The latter seems the better definition.

Samples have been examined cursorily from excavations at the Narrows Interchange Project and also from the old Celtic Club Bore on the corner of St. George's Terrace and Irwin St., Perth. Although faunas vary a little from those in the type section, the lithology appears identical and the age of P4 for the Kings Park Formation onshore is substantiated.

Overlying the Kings Park Formation at the Narrows Interchange site (Fig. 1) is a sequence of Quaternary deposits. At the base stratigraphically is the Coastal Limestone, which has

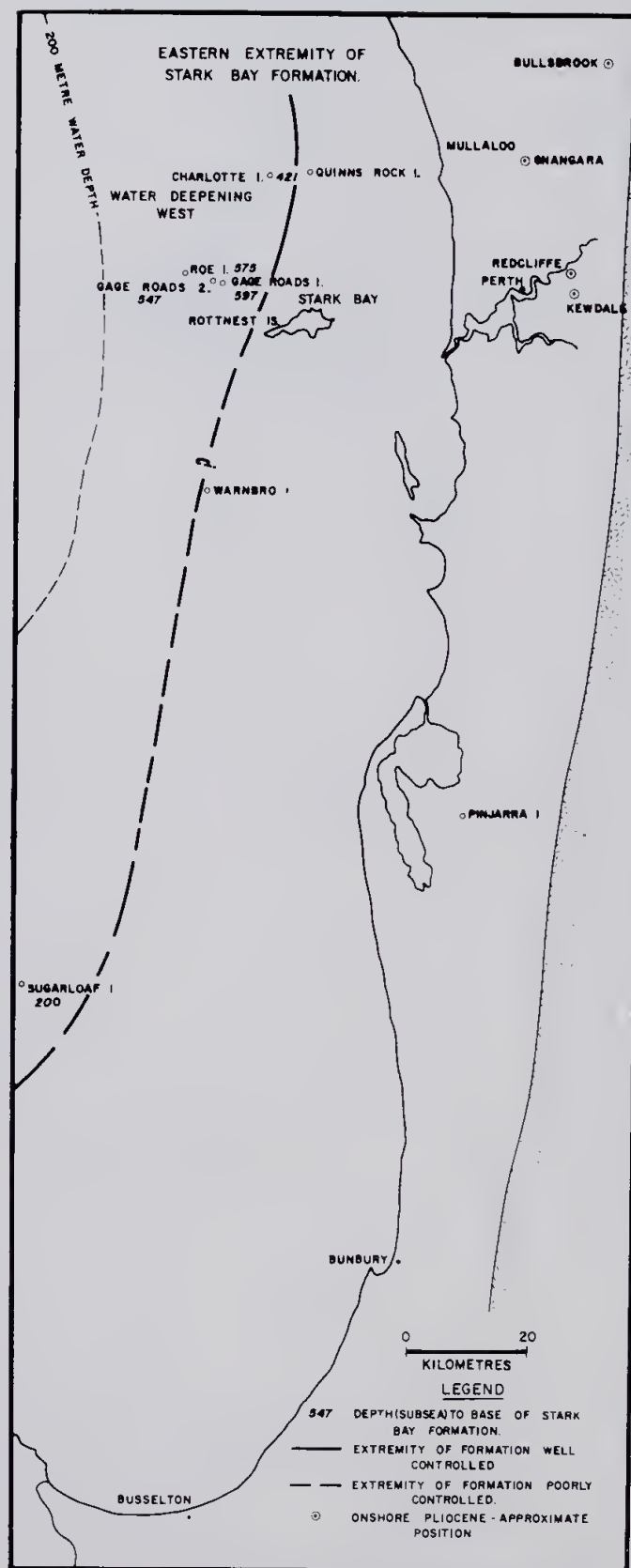


Figure 5.—Distribution of the Stark Bay Formation and of the Pliocene onshore.

been dated on Rottnest Island at about $100\,000 \pm 20\,000$ years BP (Teichert, 1967).

This formation (aeolian in the immediate vicinity) has been eroded by the Swan River and two sequences of estuarine muds succeed it. The older sequence is the more indurated and

is referred to as the "Blue Mud" by site engineers. It is distinctly older than the present sequence and contains abundant bivalves attesting to a marine or estuarine environment. No foraminifera were recovered from this material.

The younger sequence (deposited by the modern erosional cycle) is referred to as the "Black Mud".

The Quaternary sequence extends to approximately 37 m below sea level. The relationships are illustrated diagrammatically in Figure 1.

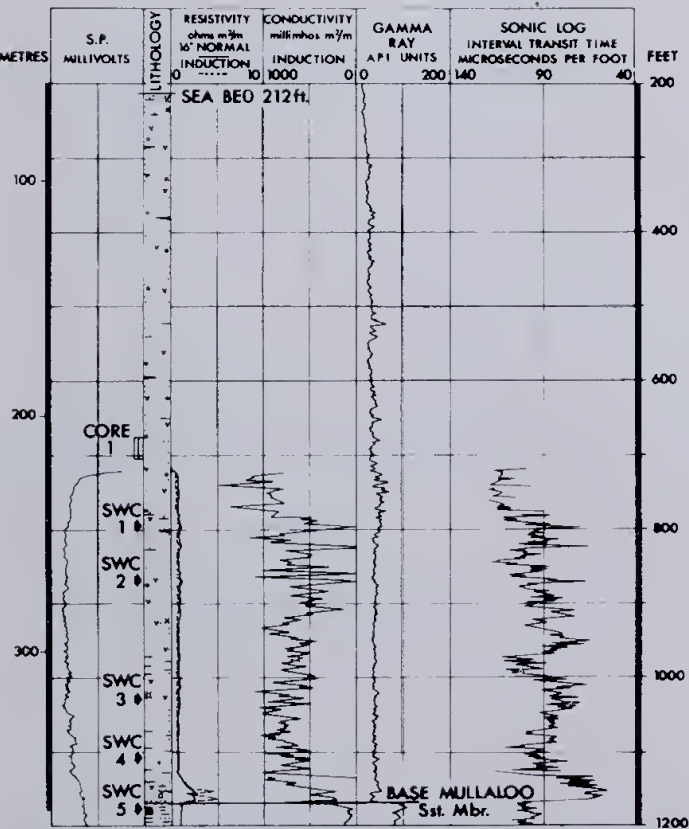


Figure 6.—Lithological and log characters of the Mullaloo Sandstone Member of the Kings Park Formation.

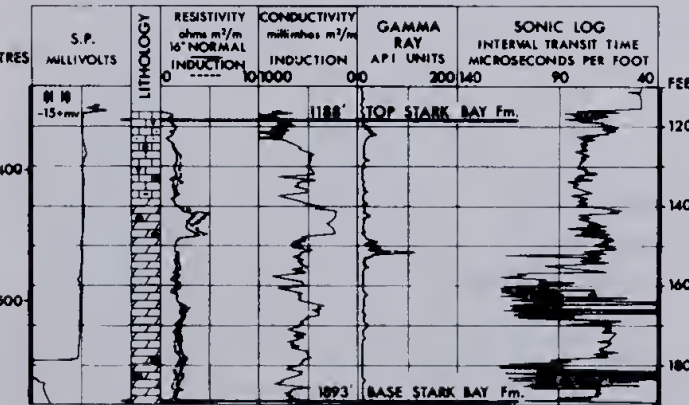
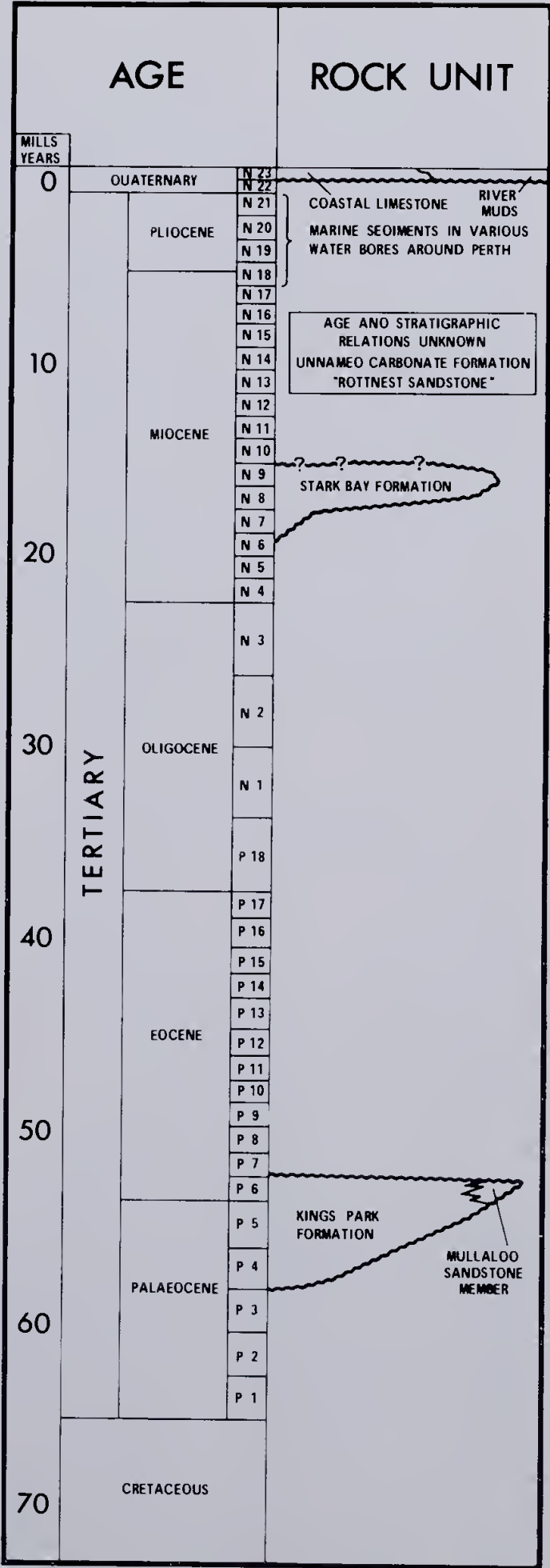


Figure 7.—Lithological and log characters of the Stark Bay Formation.

Figure 8.—Stratigraphic column for the Cainozoic of the Perth Area.



The Rottnest Island Bore (Fig. 1) was drilled in 1913 in an unsuccessful quest for artesian water. No samples were preserved between the surface and 390 m. Below 390 m cores were preserved representing the intervals marked on Figure 1.

284-666 m: *Kings Park Formation*. All cores recovered are from a lithology identical with the Kings Park Formation in its type section, although there is a slight but significant age difference between the formation on Rottnest Island and in its type section. Although there is the possibility of a stratigraphic break between the two sections, it seems probable that they are continuous and the name Kings Park Formation is taken as valid for the section in the Rottnest Island Bore.

The top of the formation (284 m) is based on drillers' records. The upper part (284-451 m) consists of grey argillaceous sandstone, and the lower part (451-666 m) of grey shale.

Only one sample from this well is present in the WAPET collections—that from the interval 486-616 m. Through the courtesy of Messrs J. H. Lord, B.S. Ingram and Dr A. E. Cockbain, of the Geological Survey of Western Australia, I have been able to examine material from the following four intervals in the Rottnest Island Bore: 451-470 m; 480-486 m; 486-616 m; and 617-666 m.

The shallowest sample contains an unidentified *Pseudohastigerina* (*wilcoxensis* or *pseudoiota*), *Globorotalia aequa* Cushman and Renz, and *Globigerina* of the *linaperta* group. This fauna indicates a *Globorotalia rex* Zone (P6) age.

The fauna from 480-486 m and 486-616 m is virtually identical. That from 617-666 m is a little different but there is no recognisable age difference. The main forms present are *Pseudogloboquadrina primitiva* Finlay, *Globigerina* of the *linaperta* group, *Globorotalia aequa* and *G. broedermanni* Cushman and Bermudez. This also supports a P6 age.

The benthonic content of all faunas is typical of the Kings Park Formation and many other sections in Australia of Palaeocene age.

71-284 m: "*Rottnest Sandstone*". McWhae (*pers. comm.*) informally used this name for "... 700 feet thickness of friable, fine to coarse, and conglomeratic sandstones, red and brown in colour and unfossiliferous, probably continental in origin".

This formation is not known outside the type locality. It also seems that no representative collections of it are available now. Thus, the name remains informal and the quotation marks used are appropriate. It could be part of the Kings Park Formation, an equivalent of the Stark Bay Formation or even younger.

0-71 m: *Coastal Limestone*. This record also is based on drillers' records and no samples are known from the well. Teichert (1967) recorded an age of $100,000 \pm 20,000$ years BP for marine fossils from this formation on Rottnest Island.

Gage Roads No. 1 was the second offshore oil well drilled in the Perth Basin.

For this study, the following samples have been examined:

Depth	Sample Type
107-116 m	DC*
116-125 m	DC
301 m	C**
302 m	C
303 m	C
329-338 m	DC
393-402 m	DC
415 m	SWC†
430 m	SWC
442 m	SWC
463 m	SWC
466-475 m	DC
472 m	SWC
486 m	SWC
502 m	SWC
512-521 m	DC
527 m	SWC
542 m	SWC
583 m	SWC
594-604 m	DC
604-610 m	DC
620 m	SWC

* Ditch Cuttings

** Conventional Core

† Sidewall Core

From these samples, from log interpretation and from wellsite sample examination, the following intervals are recognised in the well. Faunas in general are poor. The best samples for dating purposes are from 502 m and 604-610 m.

80-?100 m: *Coastal Limestone*—Pleistocene: The well spudded in Coastal Limestone whose thickness is unknown but is probably thin, certainly less than 30 m as the ditch cuttings at 94 m are of the underlying formation.

?100-389 m: *Unnamed Limestone Formation*—Pliocene-Miocene: The formation consists of yellow and pink calcarenites, clearly of biological origin in the upper region. Recrystallisation has destroyed most fossils but the shallow ditch cuttings contain abundant large foraminifera *Amphistegina lessonii* d'Orbigny and a species of *Operculina* which Barker (1960) refers to *O. ammonoides* (Gronovius). The species found here is the same as that figured by Barker but whether or not it is *O. ammonoides* is open to doubt, as was pointed out by Barker. This species makes up 60-70% of the foraminiferal fauna.

The age of the fauna cannot be defined more accurately than post-Oligocene. The sediment accumulated in warm, shallow marine conditions. The relationship of this formation with the overlying Coastal Limestone is probably unconformable. The nature of the contact with the sediment below is unknown.

389-619 m: *Stark Bay Formation* (new formation, defined later)—Early to Middle Miocene: The upper limit is taken at the marked log changes (resistivity) at 389 m and the lower limit at another marked change from the South Perth Formation (Cretaceous). Thirteen samples have been examined from this section.

The entire section is basically dolomite or dolomitic limestone, and can be divided into

two subintervals on the basis of lithological variation.

(a) 389-442 m (approximately). Dolomite unit.

This interval consists of dolomites, grey in colour, barren of foraminifera and devoid of any primary features.

(b) 442-619 m Cherty unit.

This unit also contains much dolomite but grey and brown chert is dominant in the samples seen and lithological characters are more variable than in the above section.

The chert contains abundant sponge remains and silicified calcareous fossils such as foraminifera.

The age control for the whole formation is based on the sidewall core at 502 m which contains a poorly preserved but dateable fauna. Forms present include *Globigerinoides sicanus* de Stefani, *G. quadrilobatus trilobus* Reuss, *Globigerina* cf. *G. euapertura* Jenkins and *Globorotalia obesa* Bolli. These place the fauna in the Burdigalian (upper half of the Early Miocene) or lowest Langhian (N8-N9). The fauna is 25% planktonic species suggesting deposition in 30-60 m of water. This is supported by the presence of more than 10% of bolivinid species. An interesting benthonic form in this fauna is *Pavonina triformis* Parr.

Another sample yielding a good fauna is that from the interval 604-610 m. This contains *Globorotalia barisanensis* LeRoy, *Globigerina woodi woodi* Jenkins and *Sherbornina cuneimarginata* Wade. The age is slightly older than other Miocene records, probably about N7 (lower half of *Globigerinatella insueta* Zone of Bolli, 1957).

The lower boundary of this section is marked by the log change at 619 m which represents a transition from dolomite and chert above overlying a barren, fine sandstone of Cretaceous age below.

Gage Roads No. 2

Samples examined from this well are as follows:

Depth	Sample Type
C. 305 m	Cuttings from blade of 20" bit
366 m	SWC
369-372 m	DC
396-399 m	DC
402 m	SWC
424-427 m	DC
430 m	SWC
451-454 m	DC
461 m	SWC
488-490 m	DC
515-518 m	DC
527 m	SWC
543-546 m	DC
549 m	SWC
579 m	SWC
579-582 m	DC

Lithology.—From examination of logs, ditch cuttings and sidewall cores, the following lithological divisions are recognised in the well.

1. Ground Level—? "Coastal Limestone".

The well spudded in carbonate sediment, probably still forming under marine conditions and identical with marine members of the Coastal Limestone. Its thickness is unknown, but is probably not great. Its base is not indicated on the logs. A

thickness of the order of 30 m or less is envisaged as this is a "normal" thickness for the formation.

2. ?—approximately 362 m. Unnamed carbonate formation.

Only a single sample is available from this interval. It is a bulk sample taken from the blades of the bit at about 304 m. While a poor sample, it gives some indication of the lithology at this depth. It consists of recrystallised red to yellow limestone, slightly indurated with almost all organic structure obliterated. Some forms are recognisable as foraminifera. None are identifiable. It is the same lithology as that occurring at about the same depth in Gage Roads No. 1 and Roe No. 1.

The lower boundary is taken at 362 m as there is a marked sonic log change there, and the sample at 366 m is different.

3. 362-577 m Stark Bay Formation.

3a. 362-427 m.

Several samples in this interval show that at least in part the sediment consists of white bryozoan calcarenites with rich, well preserved foraminiferal faunas. There is also grey to pale brown dolomite in most samples.

This member seems absent from Gage Roads No. 1, but a much thicker sequence is found in Roe No. 1. It may represent the original lithology of the formation, diagenesis being responsible for the lithology below.

3b. 427-514 m.

Sample control in this interval is poor, the only sidewall cores being at 430 m and 461 m. The lithology of these cores is identical and consists of saccharoidal, friable brown crystalline dolomite with minor pyrite. No fossils are identifiable. The upper and lower boundaries are selected from sonic logs.

3c. 514-544 m.

This interval is known from a sidewall core at 526 m which consists of brown, friable, saccharoidal dolomite, markedly coarser than in the interval above.

3d. 544-577 m.

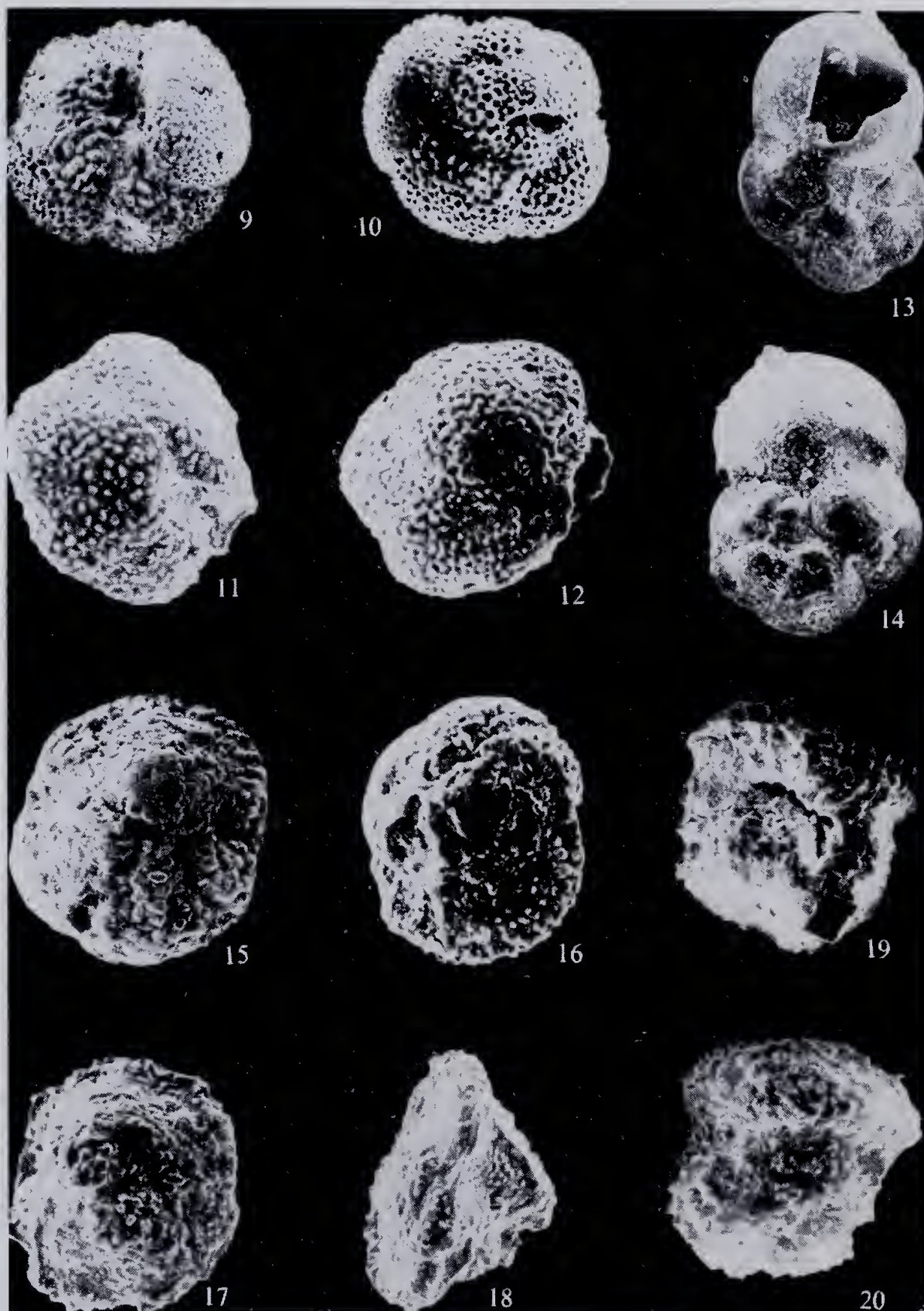
Lithology here is recorded in a sidewall core at 549 m and in a very distinctive ditch cuttings sample at 579-582 m.

Lithology in the interval is variable. The sidewall core at 549 m is a mixture of powdery white unaltered calcarenite with brown dolomite and chert. Thus, diagenetic change in this interval is not so complete as above. The sample has minor iron oxide staining.

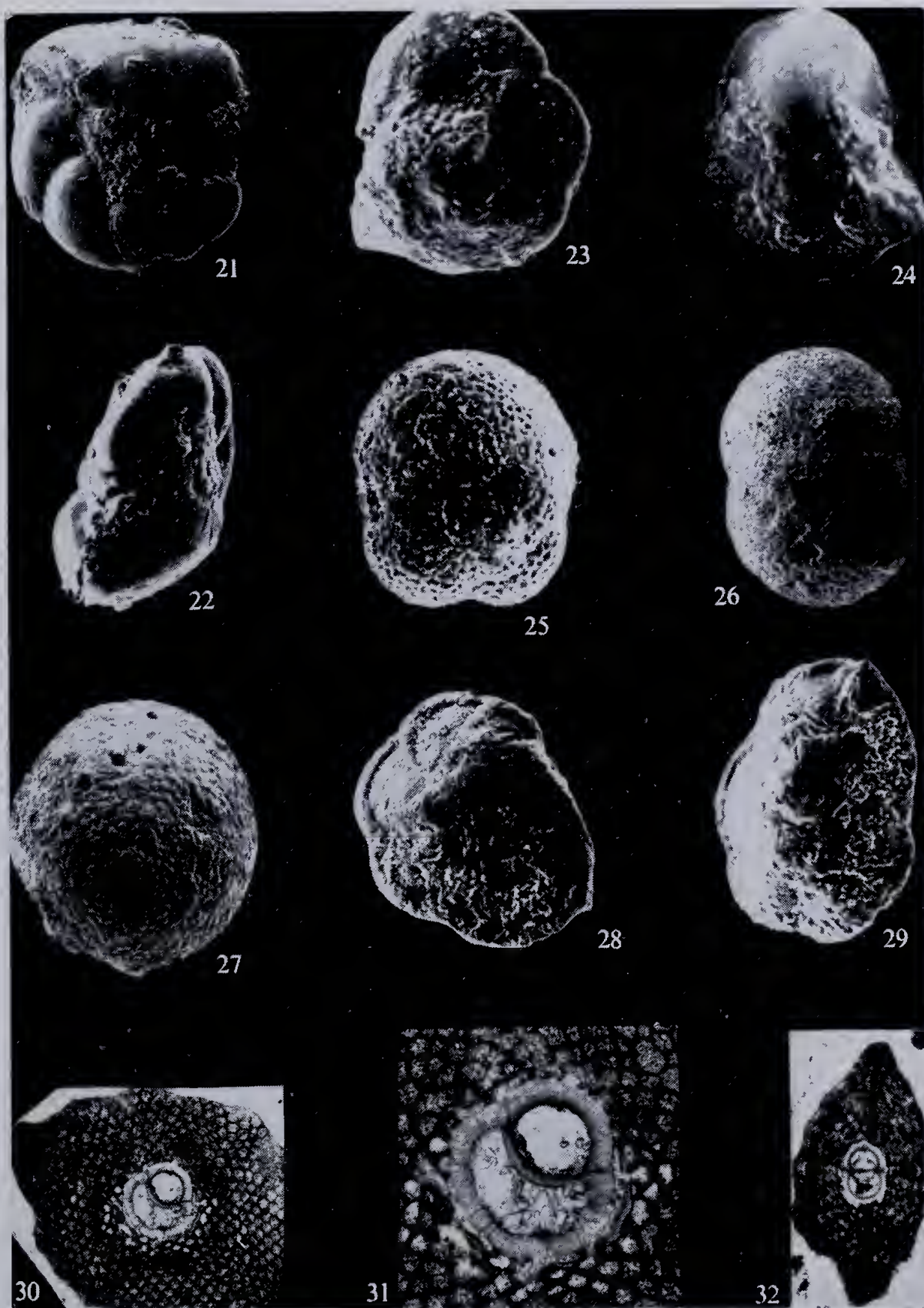
The ditch cuttings sample from 579-582 m consists almost entirely of downhole contamination, probably from just above the Cretaceous-Tertiary contact, here taken as 577 m—a sonic log pick. A sidewall core at 579 m is part of the underlying Cretaceous section. The ditch cuttings sample is partly of lightly iron-stained calcarenite with a well preserved foraminiferal fauna. The lithology and fauna are very characteristic, and have not been encountered above. They are thus probably very close to *in situ*.

The faunas.—No satisfactory faunas occur in samples above 366 m, the top sidewall core. Also, faunas in ditch cuttings between 427 m and 544 m must be suspect and probably represent downhole contamination. Thus faunas from sidewall cores at 366 m, 402 m and 549 m, as well as ditch cuttings between 366-427 m and 544-577 m, can be taken as representative of faunas at those depths. All faunas appear to belong to the N8-N9 interval of Blow (1969).

Samples from above 427 m and possible contaminated samples as deep as 518 m contain *Orbulina universa* d'Orbigny, *Globorotalia archeomenardii* Bolli, *Globoquadrina dehiscens* Chapman, Parr and Collins, and occasionally *Globigerinoides sicanus*. Thus these



Figures 9, 10.—*Globigerina mckannai* White, Warnbro No. 1, 552 m (ditch cuttings), X120. UWAGD 70421.
 Figures 11, 12.—*Globorotalia pusilla laevigata* Bolli, Warnbro No. 1, 552 m (ditch cuttings), X180. UWAGD 70422.
 Figures 13, 14.—*Globorotalia chapmani* Parr, Warnbro No. 1, 552 m (ditch cuttings), X100. UWAGD 70423.
 Figures 15, 16.—*Globorotalia dolabrata* Jenkins, Quinns Rock No. 1, 263 m (sidewall core), X130. UWAGD 70424.
 Figures 17, 18.—*Globorotalia velascoensis parva* Rey, Warnbro No. 1, 552 m (ditch cuttings), X130. UWAGD 70425.
 Figures 19, 20.—*Pseudogloboquadrina primitiva* (Finlay), Warnbro No. 1, 552 m (ditch cuttings), X165. UWAGD 70426.



Figures 21, 22.—*Pseudohastigerina* sp. Rottnest Island bore, 486-616 m, X190. UWAGD 70427.
 Figures 23, 24.—*Globorotalia pseudomenardi* Bolli, Warnbro No. 1, 552 m (ditch cuttings), X250. UWAGD 70428.
 Figure 25.—*Globigerinoides sicanus* de Stefani, Gage Roads No. 2, 582 m (ditch cuttings), X140. UWAGD 70429.
 Figure 26.—*Praeorbulina transitoria* (Blow), Gage Roads No. 2, 582 m (ditch cuttings), Xc.150. Specimen lost since photography.
 Figure 27.—*Orbulina universa* d'Orbigny, Gage Roads No. 2, 454 m (ditch cuttings), X110. UWAGD 70430.
 Figures 28, 29.—*Globorotalia archeomenardi* Bolli, Gage Roads No. 2, 399 m (ditch cuttings), X150. UWAGD 70431.
 Figures 30-32.—*Lepidocyclina* cf. *howchini* Chapman and Crespin, Gage Roads No. 2 (ditch cuttings). 30, 31.—399 m (ditch cuttings). Equatorial section, UWAGD 70432. 30 x 40, 31 x 90. 32.—427 m (ditch cuttings). Vertical section, X40. UWAGD 70433.

samples all appear to belong to N9 (approximately the *Globorotalia fohsi barisanensis* Zone of Bolli, 1957).

The deepest sample (579-582 m) is different, with *Globigerinoides sicanus* and *Praeorbulina transitoria* Blow. An age of N8 is thus indicated.

A most interesting aspect of the faunas from the upper part of the section (especially 350-425 m) is the presence of *Lepidocyclina* in ditch cuttings. The significance is discussed later.

Roe No. 1

The samples studied are from sidewall cores at 399 m, 439 m, 498 m, 537 m and 600 m. No samples are available above these depths.

The well spudded in calcarenites identical with parts of the Coastal Limestone. As in the other wells in this vicinity, it seems that the Coastal Limestone may still be forming here under marine conditions, as samples brought to the surface by divers consist of weakly consolidated shell fragments and quartz grains. The shells still retain their original colour. The formation's thickness is unknown, again probably of the order of 30 m or less.

The top four sidewall cores all contain abundant, well preserved foraminiferal faunas in a clean, white bryozoan calcarenite. There may be very minor development of chert and dolomite. This unit is the same as that seen in Gage Roads No. 2 but not in Gage Roads No. 1.

The sidewall core at 600 m has a much more poorly preserved fauna in a dolomitic unit with chert. This unit also occurs in Gage Roads Nos. 1 and 2.

The boundary between the two units is not well marked lithologically but could be taken at 552 m on a marked sonic log change. The base of the Tertiary section is well marked at 616 m by sonic and electric log changes.

The faunas.—The upper calcarenite unit contains abundant planktonic foraminifera including *Orbulina universa* (to 537 m), *Globoquadrina altispira globosa* Bolli, and *Globigerinoides quadrilobatus immaturus* LeRoy. *Globorotalia* seems to be absent. By comparison with Gage Roads No. 1, this interval can be expected to be N9 in age.

The lowest sidewall core contains a different, poorly preserved, small fauna with *Globigerina euapertura*. Also by comparison with the lower reaches of Gage Roads No. 2, and by virtue of the apparent absence of *Orbulina*, this sample may be taken as N8 in age.

Quinns Rock No. 1

The following samples have been examined from this well:

Depth	Sample Type
243 m	SWC
263 m	SWC
314 m	SWC
337 m	SWC
358 m	SWC
335-344 m	DC

Lithology.—The lithology encountered in the Tertiary section of this well is different from that encountered in any other sections discussed in this report (Figs. 2, 6).

There is no "Coastal Limestone" section and the well spudded in quartz sandstone.

65-356 m: *Mullaloo Sandstone Member* of the Kings Park Formation (defined below)—Early Eocene. The entire Tertiary section consists of sandstone which Bozanic (1969) described as "... characterized by the abundance of discrete fine to granule (2-4 mm) sized, well to very well-rounded quartz grains. The colour of the quartz is mostly clear and milky white with minor amounts of pale yellow and pale brown. Many of the grains are frosted. Sidewall cores indicate that most of the free quartz grains as observed in drilling samples are lightly cemented by argillaceous material before being drilled".

"A number of mostly fine grained but locally ranging from fine to coarse grained sandstone interbeds are present. The quartz grains vary from subangular to subrounded. Fine to medium sized grains of black glauconite are present and fine mica flakes locally common. The sandstone is variably cemented by calcareous, kaolinitic, argillaceous and pyritic material."

"Carbonaceous and lignitic streaks and fragments—often pyritized—are not uncommon."

"Siltstone zones are also developed. They are light grey, with fine and very fine black glauconite grains and cemented by calcareous and argillaceous material."

The Faunas.—All samples examined but one, are sidewall cores and thus the samples can be regarded as *in situ*.

Only two samples contain any very significant foraminifera. They are at 263 m and 314 m.

The sample at 263 m contains two identifiable specimens. They are *Globocassidulina subglobosa* (Brady) and *Globorotalia dolabrata* Jenkins. Thus this sample is Early Eocene (*Globanomalina wilcoxensis* to *Globorotalia crater crater* zones of Jenkins, 1971). Equivalence between Jenkins's and Blow's (1969) scheme is not yet precise, but the age of the sample in Blow's scheme is P6-P7 approximately, about the same age as the Eocene sediments in the Rottnest Island Bore.

The fauna at 314 m is less well dated. Again it consists of few specimens. Present are *Pseudoglobobadrina primitiva* and *G. cf. taroubaensis* Bronnimann, which support the Early Eocene age indicated for the sample above at 263 m.

The other sidewall core samples are barren except for a single "*Cibicides*" *umbonifer* Parr at 337 m. The ditch cuttings sample from 344 m contains a small, well preserved Tertiary fauna including *Globigerina triangularis* White, which is consistent with the ages determined above.

The sidewall core sample at 360 m contains a Cretaceous fauna and the base of the Tertiary is taken at the electric log-lithology change at 356 m.

Charlotte No. 1

The section in Charlotte No. 1 (Fig. 2) has been examined from the following samples:

Depth	Sample Type
329 m	SWC
332 m	SWC
332-335 m	DC
354 m	SWC
363-366 m	DC
375 m	SWC
393-396 m	DC
396 m	SWC
424-427 m	DC
462 m	SWC

Lithology.—Lithology from sidewall cores and ditch cuttings is uniform between 328 m and 396 m. The electric log characters of this interval are consistent up to 209 m. and down to 411 m. Thus the interval 200-411 m can be taken as one lithological unit.

The sidewall core at 462 m is a clean, angular, feldspathic sand shown palynologically to be Lower Cretaceous, and the ditch cuttings at 427 m (in an interval of severe circulation problems) contain much clean rounded quartz sand. Thus the Cretaceous-Tertiary boundary could be taken at the log change at 411 m. However, it is possible that the interval 411-451 m, a distinct part of the logs, is Tertiary sandstone, equivalent to the Early Eocene sands in Quinns Rock No. 1. This is unproven as no early Tertiary fossils are known from this interval. Thus the Cretaceous-Tertiary boundary could be taken alternatively at 451 m.

The following lithological units can be recognized in the well.

1. 73 m (Seabed)—93 m (approximately). "Coastal Limestone".

Material brought to the surface from the seabed consists mainly of shell fragments and may be presently forming Coastal Limestone.

2. 93 m—209 m. Lithology unknown.

This interval may be equivalent to the "Rottnest Sandstone" but no samples were taken during drilling.

3. 209-411 m Stark Bay Formation. Early to Middle Miocene.

Samples are very uniform in lithology throughout this interval. They consist of moderately recrystallised friable white to grey calcarenites with no terrigenous content. Much of the recrystallisation is to pale translucent rhombs which react readily with cold HCl. Much of the original sediment appears to be echinoderm and bryozoan debris.

Chert is virtually absent from the section except perhaps in the lower portion. Chert fragments do occur in the ditch cuttings at 427 m.

The Faunas.—Samples from the Miocene section in this well all contain almost identical faunas. *Cibicides* (*sensu lato*) makes up 50-90% of all faunas, planktonic species (undiagnostic) occur in only one sample (354 m) where they constitute only 3% of the fauna, and buliminid species make up to 24%. Other elements are chiefly cassidulinids. Benthonic species are identical with those from the Miocene sections identified elsewhere in this work. Thus a combination of lithology and benthonic fauna indicates that this is part of the Miocene sequence in the area.

The following time division is therefore possible in the well:

73-93 m	(approximately)	Quaternary
"Coastal Limestone"		
93-209 m	Unknown (?)	"Rottnest Sandstone"
209-411 m	Early to Middle Miocene	
411-451 m	? Early Eocene Sandstone.	

Warnbro No. 1

The following samples have been examined:

Depth	Sample Type
512-515 m	DC
515 m	SWC
546 m	SWC
549-552 m	DC

Lithology.—All samples are typical Kings Park Formation (Fig. 2) of calcareous shales and siltstones with abundant quartz residue. Glauconite is very common.

The sonic log character is consistent to 337 m, where the formation top is placed. An alternative top, based on gamma ray logs, could be 241 m. The lower boundary at 552 m is based on sonic logs and on lithological and faunal change.

The faunas.—The best fauna is in the sidewall core at 515 m which, while diverse, contains few age diagnostic species. The age diagnostic species *Globorotalia pseudomenardii* Bolli and *G. chapmani* Parr occur in ditch cuttings at 552 m. Thus a P4 age is indicated.

Sugarloaf No. 1

Sugarloaf No. 1 is not listed on the accompanying diagrams as no *in situ* Tertiary material was examined from the well.

The uppermost sidewall core in the well is at 321 m and this, from palynology, is a Cretaceous argillaceous sandstone. The only evidence of Tertiary seen in material from this well is in ditch cuttings at 366 m. The sample is heavily contaminated with rocks from uphole, including pale brown chert, identical with that common in Unit 1 of the Stark Bay Formation (see below).

Thus, while no Tertiary fossils have been identified from the well, the Miocene sediments of the Perth area can be inferred to be present this far south.

Stratigraphic units

Rocks of at least three different cycles of deposition occur in the area and are best discussed in the context of these cycles.

The Palaeocene-Eocene cycle

One formation with one new member is recognised in this cycle.

The Kings Park Formation (Kings Park Shale of Fairbridge, in Coleman, 1952) occurs quite extensively onshore and was defined from the interval 37-302 m in Kings Park No. 2 Bore. Where present in cores in the metropolitan area, the thickness is usually of the order of 200-250 m but in South Perth Bore it reaches about 450 m and may be even a little thicker in the Claremont area (Fig. 3).

Offshore thicknesses are 216 m in Warnbro No. 1 and 382 m in the Rottnest Island Bore.

Lithology is variable, and for this reason, the name formation is preferred to shale. The dominant rock type appears to be calcareous shale and siltstone, usually glauconitic, but in places limestone and sandy facies are dominant. Examination of lithology logs presented by Pudovskis (1962) shows that sandstone is more abundant than indicated in other literature.

The fauna includes bryozoa, foraminifera, small molluscs, rare ostracods, common sponge spicules, etc.

The age varies from place to place. All on-shore samples seen are Late Palaeocene (P4) on the basis of planktonic foraminifera. This is also the age in Warnbro No. 1 offshore. In the Rottnest Island Bore it is Early Eocene (P6). No rocks of P5 age are yet known and it may be that what is included here in the one formation could belong to two deposition cycles with a minor unconformity or disconformity between. However, until this possibility is proven or disproven, all is included in one formation. P5 could very easily be represented by a thin section and be missed in this analysis.

Whether P4 or P6 in age, the lithology and fauna are almost identical indicating a similar environment of deposition. Planktonic foraminifera are not abundant and all other faunal elements are consistent with shallow (perhaps of the order of 30 m or less) water depths, probably in a large embayment or estuary.

The *Mullaloo Sandstone Member* (new name)

Type section: WAPET's Quinns Rock No. 1 in the interval 65-356 m.

Coordinates: Latitude 31° 48' 01" S; Longitude 115° 30' 52" E.

Derivation of name: The suburb and beach of Mullaloo, approximately the closest land to the well.

Thickness: In the type section: 292 m. Elsewhere: Charlotte No. 1 (411-451 m) 40 m.

Lithology: The member consists of poorly sorted, fine to very coarse quartz sandstone with angular to rounded grains. The rock has an argillaceous matrix and commonly is slightly glauconitic. Further details of the lithology are included in the discussion of Quinns Rock No. 1.

Extent: The member is so far identified positively only in Quinns Rock No. 1 although the identification in Charlotte No. 1 is also probably correct. The sandstone in that section is of rounded quartz grains, very similar to the type section. As the lithology has not been shown to be widespread, the unit has been defined as a member only. It is the same age as the younger part of the Kings Park Formation and is continuous with it. The consistent, distinctive lithology supports its recognition as a new member.

Fauna and age: The only fossils so far recovered are rare foraminifera, including *Globrotalia dolabrata* Jenkins which indicates an Early Eocene (P6-P7) age. It is thus a lateral time equivalent of part of the Kings Park Formation.

Relations of boundaries: The upper boundary is an unconformity with the Miocene carbonates (Stark Bay Formation).

The lower boundary is an unconformity with the Lower Cretaceous sediments below.

The Miocene Carbonate cycle

The full extent of this cycle of deposition is not known. One formation (Stark Bay Formation) is defined to include the white calcarenites, brown dolomites and cherts common north and west of Rottnest Island (see below).

The relationship of the overlying red and brown calcarenites is unknown, and a new formation name may eventually be necessary to describe that unit.

The *Stark Bay Formation* (new formation) (Fig. 7)

Type section: WAPET'S Gage Roads No. 2 in the interval 362-577 m.

Coordinates: Latitude 31° 57' 05" S, Longitude 115° 21' 45" E.

Derivation of name: Stark Bay, Rottnest Island, one of the closest named geographical features.

Thickness: In the type section 215 m. Elsewhere: Gage Roads No. 1 (389-619 m) 230 m. Roe No. 1 (389-616 m) ?227 m. Charlotte No. 1 (209-411 m) ?202 m.

Lithology.—The Stark Bay Formation consists dominantly of friable white bryozoan and echinodermal calcarenite, altered diagenetically in places to brown dolomite and chert, especially in the lower parts of the formation. It formed under marine conditions with virtually no terrigenous component.

Three subdivisions of the formation can be recognized, each occurring in two or more well sections. These units probably have gradational boundaries. Thicknesses given are approximate only.

Unit 1 occurs in Gage Roads No. 1 (442-619 m) and Gage Roads No. 2 (514-544 m). It is dark brown in colour and consists of chert and dolomite in equal parts, or with chert predominant.

Unit 2 occurs in Gage Roads No. 1 (389-442 m), Gage Roads No. 2 (427-514 m) and Roe No. 1 (552-616 m). It consists of brown dolomitic limestone with subordinate chert.

Unit 3 occurs in Gage Roads No. 2 (362-427 m), Roe No. 1 (?389-544 m) and Charlotte No. 1 (?209-411 m). It is in places an unaltered white friable calcarenite, probably representing the original condition of the whole formation. Elsewhere, as in Charlotte No. 1, it is somewhat recrystallised.

Fauna and age.—The formation contains in places a rich foraminiferal fauna with abundant diagnostic planktonic species. N8 and N9 are the most common ages, but the bottom of the section in Gage Roads No. 1 may be as old as N7.

Other elements of the fauna seen are echinoderm and bryozoan fragments.

Relations of boundaries.—The lower boundary is everywhere an unconformity with either Cretaceous sediments or the Palaeocene-Eocene Kings Park Formation.

The upper boundary is not well known. The formation is overlain by a red and brown recrystallised, marine limestone of indefinite age and relationship. It may be part of the same cycle of deposition but it may be separated by an unconformity.

Repository of comparative material.—Representative portions of this formation from all sections listed are in the collections of the Bureau of Mineral Resources, Canberra, and the Geological Survey of Western Australia.

Unnamed Carbonate Formation

Overlying the Stark Bay Formation in Gage Roads No. 1, Gage Roads No. 2 and probably elsewhere, is a poorly sampled, partly recrystallised red to brown limestone or dolomitic limestone unit.

It is known from ditch cuttings at 107-137 m and in a conventional core (Core 1) at about 302 m in Gage Roads No. 1. Between these intervals is a zone of lost circulation so nothing is known from this. This lithology has also been recovered from rock chips on the bit at 305 m in Gage Roads No. 2.

The formation is marine, containing foraminifera including *Operculina* and *Amphistegina*. Its exact age, and the relationships with underlying Miocene carbonates are unknown. It is discussed further below in connection with post-Miocene sedimentation.

"Rottnest Sandstone"

McWhae (*pers. comm.*) used informally the name "Rottnest Sandstone" for sediments between 71 m and 284 m in the Rottnest Island Bore. His definition is listed under discussion of that bore.

The relationships of the formation are unknown. Drillers' records (1913) of the drilled interval record "red and brown sands". This is the record that may be expected of drilling in the unnamed red and brown carbonates above the Stark Bay Formation early in this century.

It may be that the "Rottnest Sandstone" has been misinterpreted and it may prove to be an extension of the unnamed carbonate formation or its lateral equivalent. Its possible relationships are explored further below.

Post-Miocene sediments

Scattered deposits in the vicinity of Perth

Post-Miocene sediments in the Perth Basin have been little studied to date, but Kendrick (in Darragh and Kendrick, 1971, and *pers. comm.*) has examined molluscan faunas in the vicinity of Perth from shallow water bores in such places as Bullsbrook, Redcliffe, Kewdale, Gosnells, Jandakot, Peel Estate and the Gnarup district. All contain marine faunas indicating at least two periods of sedimentation, none

older than Pliocene. The materials from Lake Gnangara is only questionably Pliocene and that from Jandakot is Pleistocene.

All the Pliocene localities listed above contain the pelagic gastropod *Hartungia typica typica* Bronn which seems certainly pre-Pleistocene (Kendrick, *pers. comm.*). The species ranges back to the Miocene and Kendrick believes that the accompanying mollusc fauna is post-Miocene. Thus, a thin Pliocene marine incursion seems reasonably widespread. The lithology is usually "a grey to yellowish calcareous sandstone, often with a high proportion of quartz grains and even pebbles of crystalline rock", (Kendrick, *pers. comm.*, 21/12/1971). No formal stratigraphic terminology has yet evolved.

Following the Pliocene, probably disconformably, is Pleistocene sediment with the bivalve *Zenatiopsis ultima* Darragh and Kendrick. The extent of the Pleistocene is as yet unknown and its relationship to other young sediments (e.g., Coastal Limestone) is not yet known completely. For purposes of this work, all the Pleistocene and Pliocene is taken as a single depositional cycle, in turn consisting of several minor episodes of sedimentation.

Coastal Limestone

Overlying the Tertiary section in coastal regions and to sea is the Quaternary Coastal Limestone consisting of aeolian and marine calcareous sandstones. This reaches a maximum thickness of 70 m in the Rottnest Island Bore. Elsewhere, it is about 30 m or less.

The maximum age so far recorded is 100 000 \pm 20 000 years BP (Teichert, 1967).

Palaeoecology and palaeogeography

Post-Miocene relationships

It is clear that the two sequences of river muds are younger than or equivalent to the Coastal Limestone and that the Coastal Limestone is very Late Pleistocene to Recent (probably still forming in several places). It is thus distinctly younger than the Pliocene calcareous sandstones although the environment of formation of the marine Pliocene may be very similar to that of the marine part of the Coastal Limestone.

The relationship of the Early Pleistocene at Jandakot (Darragh and Kendrick, 1971), the "Rottnest Sandstone" and the unnamed carbonate unit overlying the Stark Bay Formation are completely unknown and there is the possibility of lateral equivalence in part.

Palaeoecology of the Stark Bay formation

While original lithology seems constant over the area covered by this formation, the contained faunas indicate quite marked environmental differences. Faunas in almost all samples from each well have constant characters but these are different from the characters in samples from neighbouring wells. Figure 5 shows the extent of the formation.

In Charlotte No. 1, planktonic percentages are very low (0-3%) throughout the section. In

Gage Roads No. 2 they are usually in the range 20-30% and in Roe No. 1, 40-70%. Figures for Gage Roads No. 1 are more difficult to obtain accurately but are low, considerably lower than in Gage Roads No. 2. Thus, some consistent bathymetric relationship holds, with the formation in Gage Roads No. 2 and Roe No. 1 representing deeper water, more open marine facies.

From planktonic percentages above, the 30 m isobath can be placed roughly between Gage Roads Nos. 1 and 2 and seaward from Charlotte No. 1.

Percentages of *Bolivina* (*sensu lato*) in a fauna also provide a depth clue. The only wells analysed with many bolivinids are Charlotte No. 1, Gage Roads No. 2 and Roe No. 1. In Gage Roads No. 2, percentages are between 1 and 3; in Charlotte No. 1, 1-6; and in Roe No. 1, normally 20-40. Again the depth gradient exists between Gage Roads No. 2 and Roe No. 1, with the latter considerably deeper.

The high bolivinid and planktonic percentages in Roe No. 1 would indicate outer continental shelf depths of the order of 100 m or more.

The fauna in Gage Roads No. 2 is of shallower aspect, but a depth more than 30 m would be expected.

The area at Charlotte and Gage Roads No. 1 was certainly inner continental shelf.

Palaeoecology in the Palaeocene-Eocene

In the Late Palaeocene and Early Eocene, sands with some marine indicators accumulated in the vicinity of Quinns Rock No. 1 (Fig. 3). At the same time, shales, limestones, etc., were deposited in a deep embayment under Perth and to the west of the mouth of this embayment at Rottnest Island and in Warnbro No. 1.

It may be coincidence, but the Swan River now, and probably then, crosses the Darling Scarp in Walyunga National Park, due east of Quinns Rock No. 1. It is now, and probably was then, a more significant stream than either the Helena or Canning Rivers which are further south.

It is here suggested that in the Late Palaeocene-Early Eocene, a significant Swan River flowed west from Walyunga and deposited sandy sediments in the vicinity of Quinns Rock No. 1. At the same time, the Canning and Helena Rivers were smaller streams flowing into a deep embayment and depositing more argillaceous sediments.

The Swan would have migrated to its present position later.

Palaeontologically significant results

Large Foraminifera in the area

A very interesting feature of the faunas in the upper part of the Stark Bay Formation in Gage Roads No. 2 (and in that well only) is the presence of a few specimens of *Lepidocyclina* (*Eulepidina*) from samples at 399 m, 427 m, 454 m and 491 m. Unfortunately, it is not known

from sidewall cores so its exact faunal associates are not known.

The specimens are characteristically very small—up to about 1.5 mm. It occurs in association with N9 planktonic foraminifera. The significance of this record of *Lepidocyclina* is manifold.

It means that warm water seas existed in the Perth area at the time. This is an extension south of about 1 000 km of the range of this genus and these conditions in W.A. The age of the occurrence seems the same as in south-eastern Australia for *L. howchini* Crespin, and the two species are very similar. This indicates strongly that warm water seas existed all around the Australian coast at this time.

L. howchini has seemed for some years to be isolated from any other Australian occurrences of the genus and its path of migration to south-eastern Australia has been conjectural. One suggestion has been that the tropical climatic zone moved south and that migration was down Australia's east coast. It is now just as likely that migration was from the west and south coasts. This fits well the present current pattern, which probably also existed in the Miocene.

The presence of the genus means that the warm water planktonic foraminiferal zonation scheme outlined by Blow (1969) can be used in the Perth Basin at this time.

The Age of the Orbulina Datum in Western Australia

Much has been written about variations in age of the influx of *Orbulina* into various sedimentary sequences on a worldwide basis. Its absolute base is N9 (Blow, 1969). Its occurrence with *Globigerinoides sicanus* in Gage Roads No. 2 (BDC at 399 m) shows that the age there is close to the base of its absolute range and the presence of *G. sicanus* with *Praeorbulina transitoria* at 579-582 m in the same well indicates that N8 is also present. *O. universa* may occur in the well as deep as 518 m, suggesting strongly that the absolute base of the range is almost surely represented in the offshore Perth Basin.

The presence of *Operculina*, *Amphistegina* and *Lepidocyclina* indicates a warm water environment, so *O. universa* could be expected to be here at the base of its range. Carter (1964) observed that in Victoria, *L. howchini* appears stratigraphically below *Orbulina universa*. In the section studied here, they are coeval and thus three possibilities arise:

1. *L. howchini* occurs earlier in the Perth Basin than in Victoria.
2. The species is the same age in both localities but the *O. universa* influx in Victoria is later than in W.A.
3. That the absence of *O. universa* in Victoria is due merely to the normal mutual exclusion of planktonic and large benthonic species.

Note added in proof.—Since presenting this paper for publication, the Mines Department of Western Australia has drilled the Claremont Asylum No. 2 bore and recovered six sidewall cores in the Kings

Park Formation. Three of these sidewall cores (68 m, 391 m and 453 m) contain planktonic foraminiferal faunas. Those from 391 m and 453 m are typical P4 Kings Park Formation faunas but that from 68 m is different. It contains *Globorotalia rex*, *G. cf. quetra*, *G. aequa*, and the important zonal species *G. pseudomenardii* and *G. chapmani* are absent.

It is probable that this fauna is P6 in age, the same as the Kings Park Formation in the Rottnest Island Bore and in Quinns Rock No. 1. It is thus the first record of rocks of this age onshore in the Perth area.

The fauna occurs in a well developed sandstone unit at the top of the Kings Park Formation. This sandstone probably can be referred to the Mullaloo Sandstone Member.

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5.—The petrology of the Wooramel Group (Lower Permian) in the Lyons River area, Carnarvon Basin, Western Australia.

by Gerard J. McGann¹

Manuscript received 18 July 1972; accepted 19 February 1974

Abstract

In the Lyons River area, about 100 miles east of Carnarvon, Western Australia, the Wooramel Group (Lower Permian) comprises the Moogooloo Sandstone and the Billidee Formation. The Moogooloo Sandstone, overlying the Callytharra Formation with a conformable, disconformable or faulted contact, consists of orthoquartzite, often ferruginized, with minor orthoconglomerates. Gypseous carbonaceous shales are present towards the top of the formation.

The Billidee Formation, resting conformably on the Moogooloo Sandstone consists of fine to medium grained orthoquartzite and calcite-cemented sandstone, interbedded with gypseous carbonaceous shale. A laterally-persistent, fossiliferous unit is present at the top of the formation.

Introduction

The name "Wooramel Group" was first proposed by Condit (1935) and revised by Konecki *et al.* (1958) who described it as "... predominantly arenaceous sequence disconformably or unconformably overlying the Callytharra Formation, Lyons Group or Precambrian schist, or overlain conformably by, or changing laterally into the Byro Group." In the Lyons river area, only two formations of the Wooramel Group, the Moogooloo Sandstone and the Billidee Formation are exposed. No previous detailed work has been done on the Wooramel Group in the Lyons River area, although the area has been regionally mapped by the Bureau of Mineral Resources (Condon 1954, 1962, 1967).

An area about 110 miles east of Carnarvon, Western Australia (Fig. 1) was mapped in 1970. Rocks exposed are the Precambrian rocks of the Weedarra Inlier, and Permian rocks—the glaciogene Lyons Group, the Callytharra Formation and the overlying Wooramel Group. Mapping was done by numerous ground traverses with the aid of aerial photographs. Twelve stratigraphic sections were measured. About 70 thin sections were examined with a petrological microscope. Some friable rocks were impregnated with plastic or Canada balsam before sectioning. Sediments are classified according to Pettijohn (1957).

Topography

The topography of the Lyons River area closely reflects the distribution of rock types. The Moogooloo Sandstone outcrops strongly as a strike ridge and dip slope, or as mesas and

buttes. The sandstone lithologies of the Billidee Formation outcrop as low strike ridges, and the interbedded shales do not outcrop.

Stratigraphy

The Lower Permian stratigraphy of the Lyons River is summarised in Fig. 2. The outcrop pattern and inferred subsurface extent of the Wooramel Group which, in the Lyons River area, comprises the Moogooloo Sandstone and the Billidee Formation, is shown on Fig. 3.

Structure and Tectonic History

The area mapped is in the south-easterly corner of the Merlinleigh Basin and in the west of the Bidgemia Basin, both sub-basins in the eastern Carnarvon Basin. The Weedarra Inlier (Precambrian) is the dominant structural element in the area mapped. Permian sediments are down faulted against the inlier by major faults. The Permian sediments strike north-south and dip to the west at about 5 degrees. Faulting is common in the Permian sediments. There are two dominant trends: strike faults, and faults trending at about 280 degrees. Most of these faults have a throw of less than 46 m.

Petrology of the Wooramel Group

In the Lyons River area, the Wooramel Group comprises the Moogooloo Sandstone and the overlying Billidee Formation. The group is dated as Artinskian (Early Permian).

Moogooloo Sandstone

The Moogooloo Sandstone consists of red, brown and white fine to coarse-grained orthoquartzites; subordinate arkoses (feldspathic sandstones) and orthoconglomerates. Minor interbedded silty shales are present in the upper part of the formation.

Orthoquartzite is the dominant lithology, grading compositionally into subarkose. Grain size ranges from 0.05 mm to 1.8 mm, with the majority of grains in the 0.2 to 0.5 mm range. Secondary overgrowth has resulted in many originally rounded grains becoming subangular. Sorting is moderate to good.

The dominant mineral in the sandstone suite is quartz, commonly with undulose extinction. Syntaxial growth on quartz grains is present in every sample examined. Pressure welding is observed in some juxta-positioned grains. Inclusions in quartz include tourmaline, zircon and muscovite. Microcline is the only feldspar present, and ranges in abundance from almost nil

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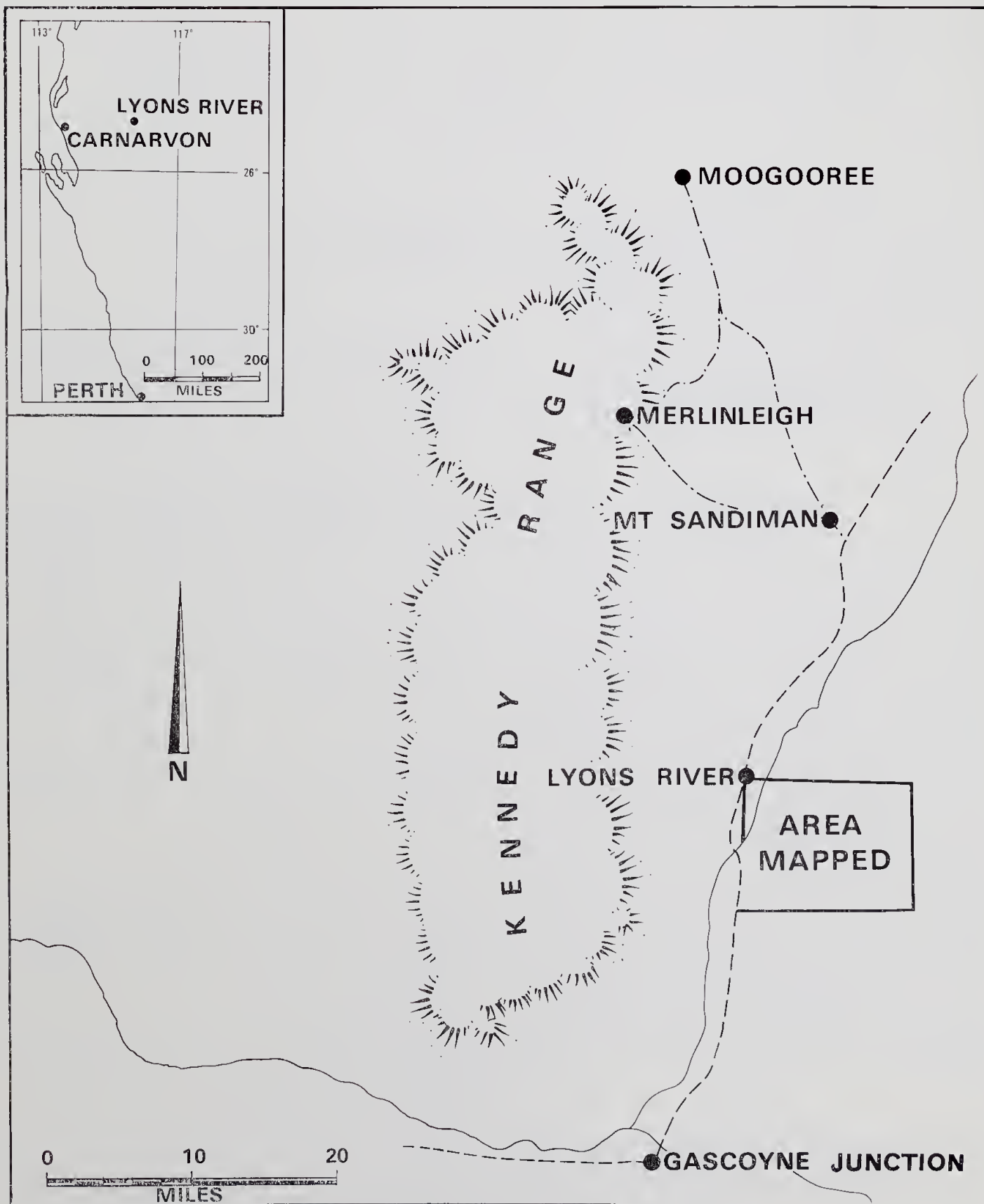


Figure 1—Locality map.

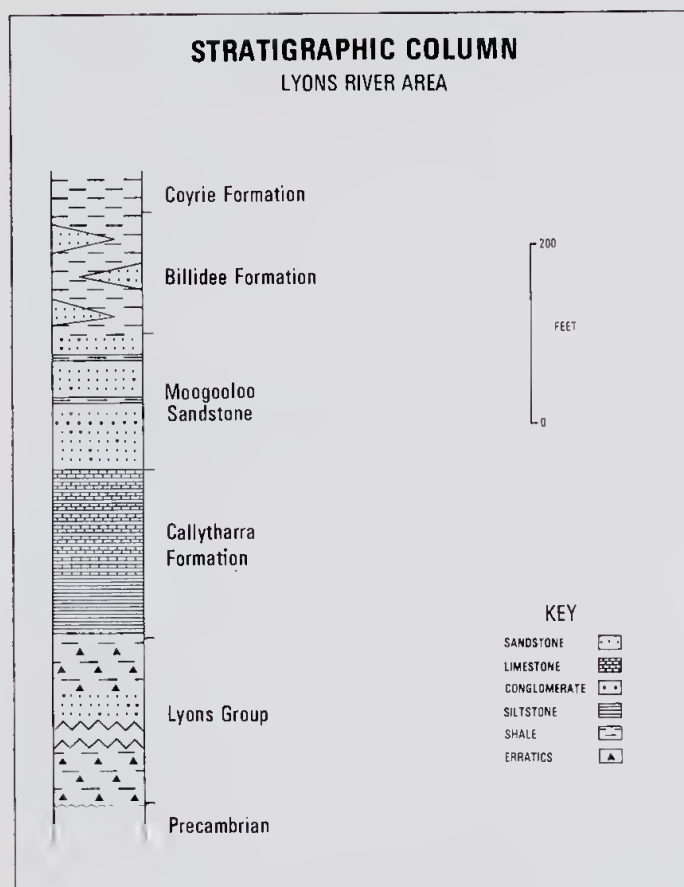


Figure 2—Stratigraphy of the Lyons River area.

to 9% of the detrital fraction. Lithic fragments are present in over 60% of the orthoquartzites, and in all of the subarkoses examined, fine-grained metaquartzite being by far the most abundant. Muscovite is a common detrital grain, in plates up to 1.3 mm long. Light-brown biotite is a common accessory.

No systematic study of the heavy mineral suite was undertaken, but a number of heavy mineral samples were examined. Euhedral to subhedral zircon and tourmaline are the most abundant minerals. Tourmaline is present in pleochroic yellow-green and dark grey-pink varieties. Both pink and colourless garnet are present. Rutile, sphene and staurolite are minor accessories. The detrital opaque minerals are ilmenite, with partial leucoxene coatings, and minor limonite.

The matrix is dominated by kaolinite, either coating grains or filling all interstitial spaces. In some samples, the clay has been completely ferruginized, resulting in a rock with a high proportion (up to 22%) of hematite with some limonite. Chlorite, sericite, microcrystalline quartz, gypsum, collophane and calcite are all minor, probably authigenic, constituents of the matrix.

Orthoconglomerates are volumetrically a very minor constituent of the Moogooloo Sandstone, occurring in beds up to 30 cm thick which persist laterally for up to 120 metres. The conglomerates are poorly sorted, the grain size ranging from 0.02 mm to 4 cm. The dominant detrital

mineral is quartz, with minor secondary overgrowths. Other minor detrital grains are fresh microcline feldspar and lithic fragments. The matrix is made up entirely of hematite and minor limonite.

Dark-grey to brown, friable, carbonaceous silty shales occur near the top of the formation in beds up to 1.8 metres thick. The shales are interbedded with coarse-grained orthoquartzites and conglomerates containing the trace fossil *Palaeophycus* sp. The shales are poorly laminated and contain up to 15% carbonaceous matter. Silt-sized detrital grains, mainly quartz, are concentrated in lamellae up to 0.1 mm thick. Gypsum accounts for up to 12% of the mode, in laths up to 50 mm long, and is thought to be a primary mineral, although some recrystallization has occurred. Slight ferruginization has partially welded the clay-sized particles together.

Diagenesis is here discussed under three headings:

- (a) Constructive diagenesis.
- (b) Destructive diagenesis.
- (c) Compactional effects.

The discussion is here confined to the more abundant sandstone suite.

(a) Constructive diagenesis. Under this category are grouped all diagenetic mineral growths and enlargements. The development of syntaxial

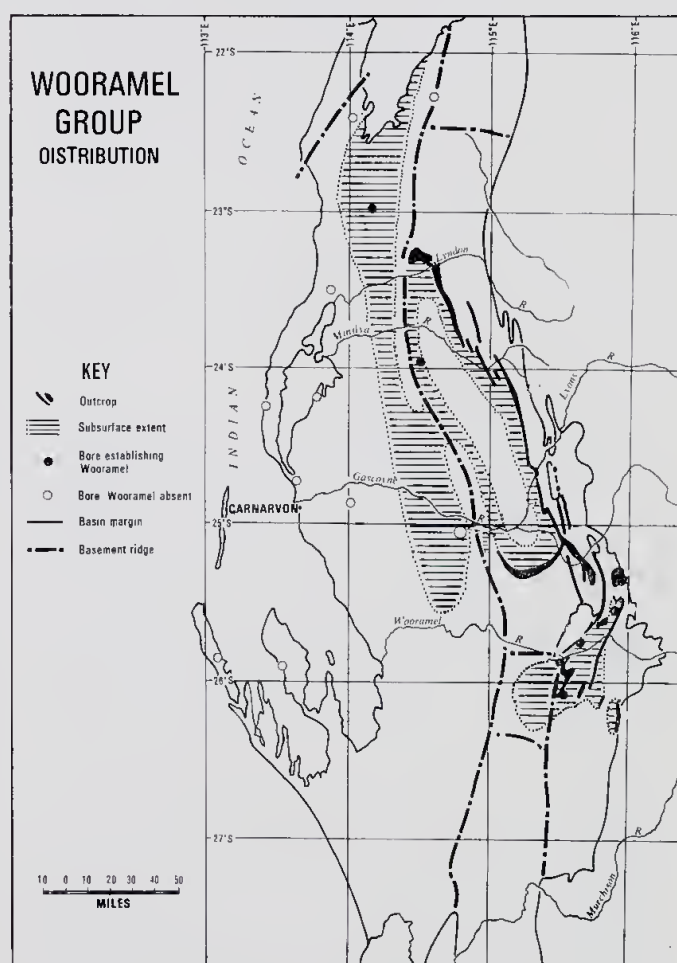


Figure 3—Distribution of the Wooramel Group (After Condon, 1967).

rims on quartz is the most common of these effects. Other diagenetic minerals are kaolinite, hematite and limonite, sericite, collophane, microcrystalline quartz, chlorite and calcite. Hematite and limonite were deposited after kaolinite, growing preferentially in the kaolinitic clay matrix.

(b) The principal destructive effect is the etching of quartz and feldspar by kaolinite. Hematite and limonite, where abundant, also etch quartz and feldspar. Tourmaline suffers noticeable solution, only fragments of once large detrital grains remaining.

(c) Compactional effects observed are bending of muscovite plates around detrital grains, and pressure welding of quartz grains at points of contact. The material which has been removed from areas of solution is thought to have been redeposited as syntaxial growths.

Billidee Formation

The Billidee Formation conformably overlies the Moogooloo Sandstone, and consists of orthoquartzites and calcite-cemented sandstones. Gypseous, carbonaceous silty shales, similar to the shales of the Moogooloo Sandstone, make up about 45% of the formation. Rare siltstones, often calcareous, and calcareous conglomeratic sandstones are also present. None of the units within the formation has any lateral persistence except the uppermost calcareous sandstone unit which contains abundant pelecypods. This is the only unit which can be traced along strike for more than 460 m. The uppermost unit is up to 6 m thick, persists throughout the whole of the area mapped, and is the only mappable unit in the formation. Fossils (apart from fossil wood) are found only in this unit.

All of the sandstones are thinly bedded, with bedding thicknesses ranging from 2.50 to 60 cm. They are predominantly fine to medium grained, the mean grain size being 0.2 mm. Nearly all of the sandstones are moderately well sorted, with moderate to poor rounding and low sphericity of detrital grains.

Quartz, often with undulose extinction, is the dominant mineral, averaging 60% of the mode. Fresh and slightly altered microcline comprises up to 40% of the mode, in grains up to 1.5 mm in diameter. Muscovite is common accessory, in plates, often bent by pressure, up to 0.4 mm long. Light-brown, slightly pleochroic biotite is present in some specimens. In one fine-grained orthoquartzite, recrystallized primary gypsum is interbedded with detrital quartz. Rare limonite pseudomorphs after pyrite are present in grains up to 1 cm in diameter. Oligoclase is present in one thin section.

Lithic fragments present in the sandstones include chert and occasional fragments of quartz-muscovite schist up to 14 cm in diameter, in the uppermost unit of the formation. Rare carbonate lithic fragments occur, some containing unidentified Bryozoa, punctate brachiopods (perhaps *Permorthotetes* sp.) and also an unidentified calcareous alga. The lithic fragments are partially replaced by sparry calcite in isolated, often lenticular, patches. The carbonate

lithic fragments contain between 3% and 20% sandsized detrital grains admixed with the carbonate, and are extensively ferruginized and cut by ferroan calcite veins. Rare ferroan calcite lithic fragments containing quartz and authigenic microcline are present in some calcite-cemented sandstones.

The non-opaque heavy mineral suite, in order of abundance, is tourmaline, zircon, colourless and pink garnet, rutile, sphene, staurolite and barite. The opaques are limonite and minor ilmenite.

There is great variety in the matrix of the sandstones of the Billidee Formation, with calcite, ferric oxides, clay minerals and chlorite all being major constituents in different rocks.

Calcite cement is present in a large number of the sandstone bodies within the formation. The cement consists of crystalline ferroan calcite, with patches of non-ferroan calcite and admixed clay minerals. The ferroan calcite cement consists of interlocking crystals, some up to 9 mm in diameter. In many of the calcite-cemented sandstones, the detrital grains are "floating" unsupported in the calcite matrix. Evidence of pressure solution is widespread, and suggests that the sediment was grain supported when deposited, with a relatively high proportion of detrital skeletal fragments. Pressure solution has been applied, either by sedimentary load or by tectonic stress, and has resulted in the solution of the carbonate skeletal fragments. Dissolved carbonate has been reprecipitated as ferroan calcite, producing the unsupported "floating" texture. The iron necessary for the production of ferroan calcite may have been derived from clay minerals, as outlined by Oldershaw and Scoffin (1967). Some skeletal fragments have escaped solution, especially in the uppermost unit of the formation.

Non-ferroan calcite is a minor constituent of the matrix, occurring as coatings, up to 0.03 mm thick, on detrital grains, and as isolated patches within ferroan calcite. There are two possible explanations for the origin of this non-ferroan calcite, the first being that the patches are remnants of original skeletal grains that have escaped pressure solution, and thus have not been converted to ferroan calcite. The second alternative is that calcite has been dissolved by pressure solution and reprecipitated, but because of an oxidizing micro-environment around detrital grains and in isolated patches, non-ferroan calcite has been deposited instead of ferroan calcite. Ferroan calcite can be deposited only in reducing conditions (Evamy, 1969). The second explanation is favoured by the author.

Ferric oxides are abundant in the matrix of some orthoquartzites, with hematite and limonite occupying up to 35% of the rock. The average is, however, about 4%.

Minor clay minerals are common in the matrix, occurring in isolated patches, often partially ferruginized. Colourless chlorite is a common matrix mineral, in scalar aggregates up to 1 mm in diameter, occupying up to 10% of the rock, the average being about 1%. The matrix also contains minor gypsum, in scalar aggregates.

Pressure effects are abundant in the Billidee Formation, with pressure welding of quartz and microcline grains, bending of micas and pressure solution of calcite. Quartz, and some microcline grains show secondary overgrowths, the material for the overgrowth probably being derived from pressure solution. In sandstones with abundant calcite cement, authigenic secondary growths are rare, and etching of quartz is common.

The fossils of the uppermost member of the Billidee Formation are recrystallized into blocky calcite, sparry in places. Dark lamellar organic matter (conchilium) is still present in many valves of *Oriocrassatella* sp., and is seen to pass through the sparry calcite, indicating that the spar is formed by replacement. *Oriocrassatella* sp., is also partially replaced by ferroan calcite in quite irregular patches. Replacement of calcite by ferroan calcite has, to the author's knowledge, not previously been recorded in the literature.

Borings, perhaps algal, are common in some pelecypods in the uppermost unit in the formation, penetrating up to 0.4 mm into the valve. The borings are infilled with ferroan calcite, of different composition (less iron) than the replacement ferroan calcite mentioned above.

Late-stage diagenetic effects observed in the Billidee Formation are ferruginization, sparry calcite veins and sparry infillings of fossils, together with the development of calcrete.

Acknowledgements.—The author is deeply indebted to WAPET Pty. Ltd. and to the University of Western Australia for funding the project. Sincere thanks must also go to Dr. B. W. Logan and members of the University staff, fellow honours students, and also the manager and staff of Lyons River Station.

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6.—An annotated list of lichens from the coastal limestone near Perth, Western Australia

by N. C. Sammy¹ and G. G. Smith¹

Manuscript received 18 July, 1972; accepted 16 April, 1974.

Abstract

Records of distribution are given for thirteen lichen species of the genera *Aspicilia*, *Buellia*, *Caloplaca*, *Dermatocarpon*, *Diploschistes*, *Fulgensia*, *Lecidea*, *Leptogium*, *Toninia*, *Verrucaria* and *Xanthoria* occurring in the limestone belt along thirty miles of coastline near Perth, Western Australia.

The habitat preferences and frequency of each species are evaluated.

Introduction

The Swan Coastal Plain is a narrow strip of sandy country along the coast of South-Western Australia. It is composed almost entirely of fluvial and eolian sediments derived originally from the PreCambrian land mass, the western edge of which is called the Darling Scarp. The western border of the plain is composed largely of the Spearwood Dune System of Pleistocene age and is partially overlain on its seaward edge by a very narrow coastal strip of Post-Glacial and contemporary sands of the Quindalup Dune System (McArthur and Bettenay 1960, Fairbridge 1950).

The Spearwood Dunes have a core of calcareous eolianite (locally called the Coastal Limestone) and residual brown and yellow sands resulting from leaching of the carbonate from the rock core. The limestone is heterogeneous in that it has varying proportions of siliceous grains and calcareous fragments of marine organisms bound by fine calcareous cement. Much of this limestone is porous, friable and often stratified and cross-bedded (Figure 1). Fine grained travertines have been secondarily deposited in the eolianite and are exposed abundantly along the coast as karst features in the forms of hard, gray mantles, solution pipes and pinnacles (Figure 2). Aerial erosion of the eolianite and the travertines results in pitted and jagged rock surfaces. The sea cliffs mostly have the more highly incised form of weathering, especially in the extreme upper littoral where both physical and biological agencies of marine erosion are strongly active (Figure 3).

This much-dissected form of the Coastal Limestone with its richly convoluted surfaces provides a large variety of ecological niches for lichens occurring upshore from the splash zone of the extreme upper littoral where *Verrucaria maura* Wahl. occurs. The limestone exposures of the metropolitan sector of the coast were investigated for their lichen flora, the region sampled including some thirty miles of the coast

between Cape Peron South (locally called Point Peron) and North Beach. Also included in the survey were limestone sites at Garden and Rott-nest Islands near Fremantle, limestone cliffs of the Swan River Estuary and a single outcrop at Point Mount Henry on the Canning River (Figure 4). Some of the species on limestone also occur on wood and bark of trees and shrubs in the vicinity, and these occurrences are also recorded.

Thirteen species of lichens were collected from the study area, and of these the most abundant were *Buellia alboatra* (Hoffm.) Branth. and Rostr., *Fulgensia bracteata* (Hoffm.) Räs., and *Xanthoria ectanea* (Ach.) Räs. ex R. Filson. The voucher specimens cited here are kept in



Figure 1.—Limestone cliffs at Point Mount Henry, showing bedding planes.

¹ Botany Department, University of Western Australia, Nedlands, W.A. 6009.

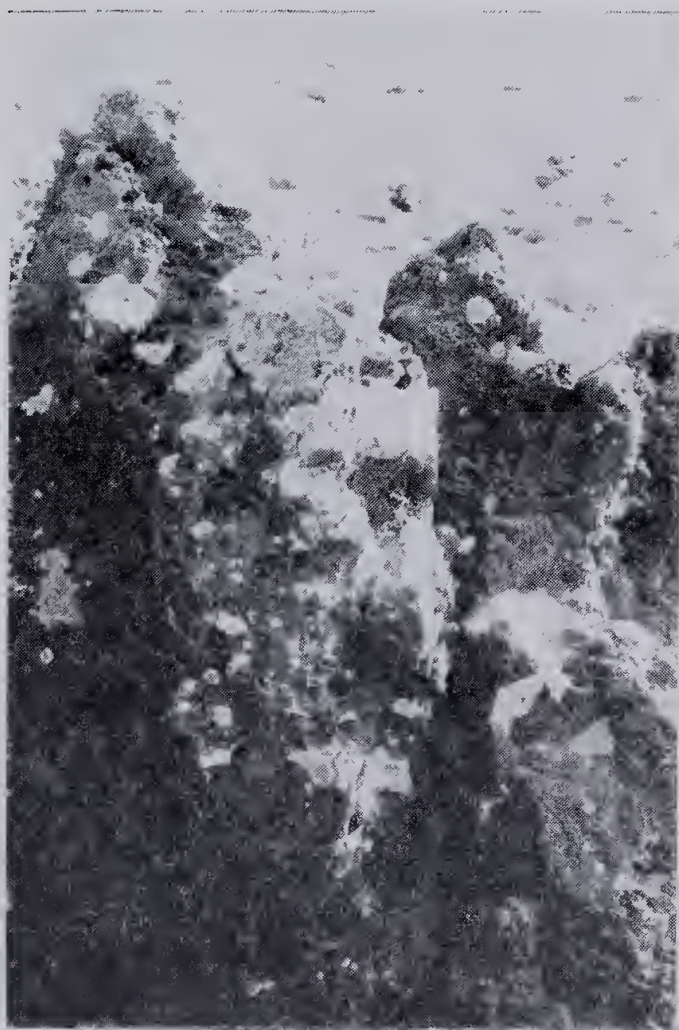


Figure 2.—Travertine limestone at North Beach with *Buellia alboatra*. This limestone is a few feet above high water mark of winter storm tides (beach in the background).

the Herbarium of the Botany Department, University of W. A. (UWA).

The classification used below is that of Mat-tick (1954).

ASCOLICHENES

Verrucariaceae

Verrucaria maura Wahl., in Ach. Meth. Lich. Suppl. 19. (1803). Occasional, as a black to dark green, encrusting growth immediately above the littorinid zone of *Melaranghe unifasciata* (Gray) in the splash and spray zone of the extreme upper littoral of limestone sea cliffs. Cape Peron South (UWA 666, UWA 624); Garden I., at the southern end (UWA 1044) and at Entrance Point (UWA 1049, UWA 1050); Rott-nest I., at Radar Reef (UWA 1093); Cottesloe, at Mudurup Reef (UWA 1397); North Beach (UWA 714).

Dermatocarpaceae

Dermatocarpus hepaticum (Ach.) Th. Fries in Nova Acta Reg. Soc. Scient. Upsalla, ser. 3, VII: 355 (1861).

Endocarpus hepaticum Ach. in Kgl. Vet. Akad. Nya Handl., 156 (1809); and Lichen. Univers. 298 (1810).

Common on friable limestone and on shallow soil overlying limestone, usually in shaded sites. Limestone cliffs of the Swan River Estuary at Kings Park (UWA 733), Rocky Bay (UWA 793, UWA 1029) and Point Roe (UWA 794). Rott-nest I., common on limestone about the salt lakes (UWA 1097, UWA 1087).

Diploschistaceae

Diploschistes scruposus (Schreb.) Norm. in Nyt Magazin for Naturv. 7: 232 (1853).

Urceolaria scruposa (Schreb.) Ach. in Lich. Suec. 32 (1798). *Lichen scruposus* Schreb., in Spic. Fl. Lips. 133 (1771).

Common on limestone cliffs of the Swan River Estuary at Kings Park (UWA 626) and Rocky Bay (UWA 793, UWA 795).

Collemaaceae

Leptogium phyllocarpum (Pers.) Mont., Ann. Sci. Nat. Bot. III, 10: 134 (1848).

Collema phyllocarpum Pers. in Gaud. Voyag. Uranie, 264 (1826).

Rare. Rottnest I., on limestone at Lake Her-schell (UWA 1096); North Beach, in moss swards on limestone (UWA 717); Point Mount Henry, on trunk of Tuart tree (*Eucalyptus gompho-cephala* DC.) (UWA 607); Kings Park, on trunks of Tuart trees (UWA 1009); Yanchep, in moss swards on limestone at Silver Stocking Cave (UWA 1030).

Lecideaceae

Lecidea decipiens (Ehrh.) Ach. Method. Lich. 60 (1803) and Synops. Lich. 53 (1814).

Psora decipiens (Ehrh.) Hoffm. in Deser. Pl. Crypt. 2: 63 (1794).

Biatora decipiens (Ehrh.) E. Fries in Lichen. Europ. Reform. 252 (1831).

Lichen decipiens Ehrh. in Hedw. Descr. et Adumbr. Muscor. Frondos 2: 7 (1789).

Occasional on soil overlying limestone out-crops along the Swan River Estuary, Rocky Bay (UWA 798); Rottnest I., on indurated limestone at Lake Herschell (UWA 1086). Preiss collected



Figure 3.—Sea cliff at Mudurup Reef, Cottesloe, at low tide, showing incised form of weathering. *Verrucaria maura* occurs sparsely in the supra-littoral below the visor or overhang of the cliff.

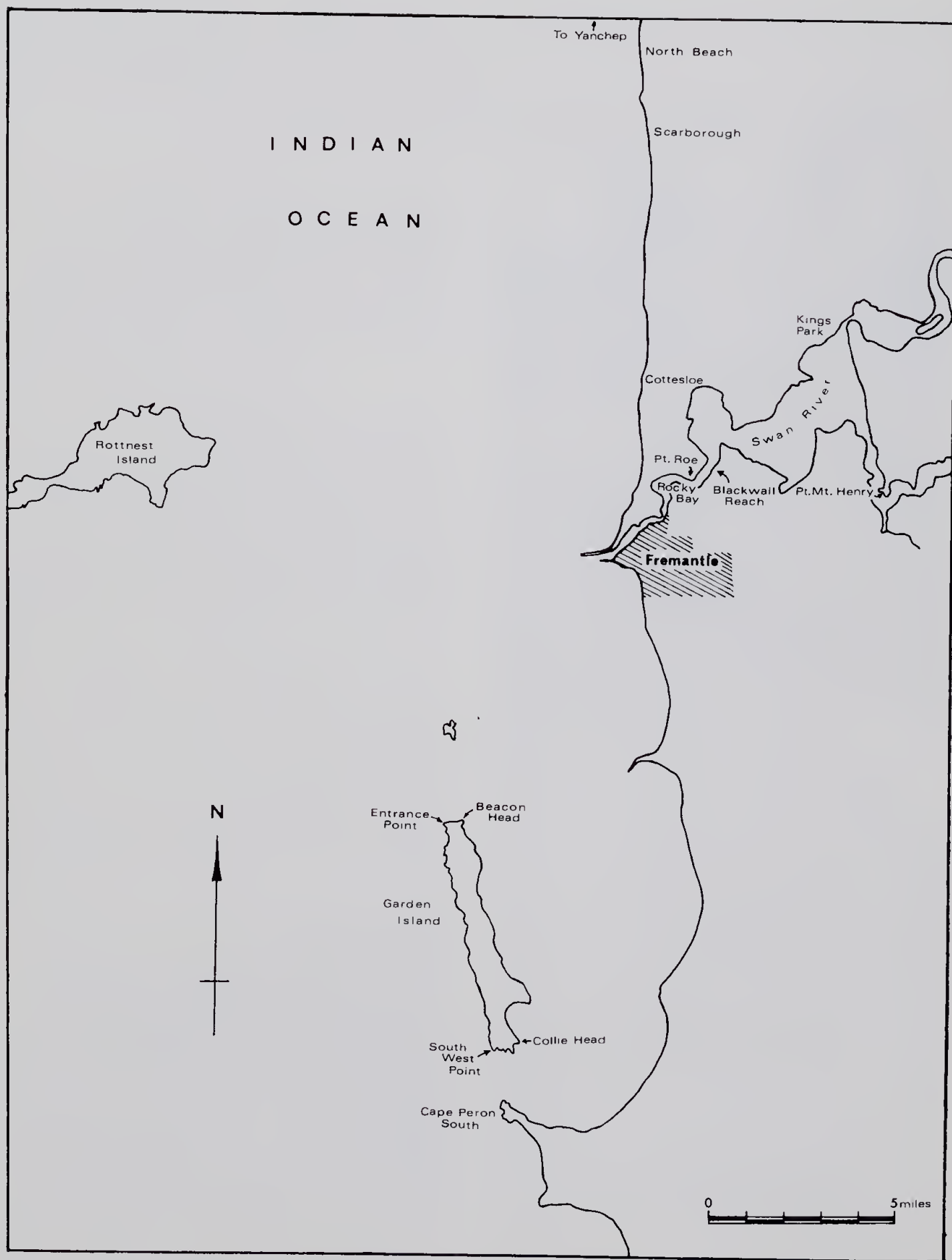


Figure 4.—Locality map of the study area.

this species from sandy soil near a lake at Rottneest I. (Fries 1846).

Lecidea plana (Lahm) Nyl. in Flora 55:552 (1872).

Lecidella plana Lahm in Koerb. Par. Lich. 211 (1865).

Frequent on coastal limestone, but easily overlooked. Point Roe in the lower Swan River Estuary (UWA 799); Cape Peron South (UWA 1051); Rottneest I., on indurated limestone along the banks of Lake Herschell (UWA 1085).

Toninia cumulata (Sommerf.) Th. Fries in Lich. Scand. I: 341 (1874).

Lecidea cumulata Sommerf., in Suppl. Flora Lapp. 157 (1826).

Lecidea conglomerata Sommerf., in Egl. Vidensk. Skrifter II; 54 (1827).

Occasional on limestone at Cape Peron South (UWA 1052); North Beach (UWA 1053); Garden I.; Rottneest I., on friable limestone sea cliffs at Radar Reef (UWA 1089, UWA 1054); Point Mount Henry (UWA 606).

Lecanoraceae

Aspicilia calcarea (L.) Mudd, Manual Brit. Lich. 161, tab. III, (1861).

Lecanora calcarea (L.) Sommerf. in Suppl. Flor. Lapp. 102 (1826).

Lichen calcareus L. in Sp. Pl. 1140 (1753).

Garden I., abundant on sea cliffs at Collie Head (UWA 1036, UWA 1040, UWA 1041); Rottneest I., sea cliffs at Geordie Bay (UWA 1083), limestone outcrops at Serpentine Lake (UWA 1098) and indurated limestone at Lake Herschell (UWA 1084). Apparently rare on the mainland. Cape Peron South, on limestone cliff (UWA 664).

Caloplacaceae

Caloplaca aurantiaca (Lightf.) Th. Fries in Nova Acta Reg. Soc. Scient. Upsalla, ser. 3, III: 219 (1861); and Lichen. Scand. I: 177 (1871).

Lichen aurantiacus Lightf., Flora Scotica II: 810 (1777); edit. 2, 810 (1789).

Common on limestone and also on bark and wood of coastal shrubs. North Beach (UWA 716); Scarborough (UWA 1027); limestone cliffs of the Swan River Estuary at Point Roe (UWA 796); Blackwall Reach (UWA 1028); Rocky Bay (UWA 795); Kings Park (UWA 849); Garden I., on cliffs at Beacon Head (UWA 1047, UWA 1048); Rottneest I., abundant on limestone about the salt lakes (UWA 1092) and on sea cliffs at Radar Reef (UWA 1088).

Fulgensia bracteata (Hoffm.) Räs., in Die Flecht. Estl. I: 108 (1931).

Caloplaca bracteata (Hoffm.) Jatta in Sylloge Lich. Ital., 236 (1900).

Psora bracteata Hoffm. in Deutschl. Flora 2: 169 (1796).

Common and often abundant on limestone cliffs at Kings Park (UWA 1045); Point Mount Henry (UWA 608, UWA 611); Rocky Bay (UWA 793); Rottneest I., on friable limestone sea cliffs (UWA 861) and on limestone outcrops at Lake Herschell (UWA 1095).

Teloschistaceae

Xanthoria ectanea (Ach.) Räs ex R. Filson in Muelleria 2: 65 (1969).

Xanthoria ectanea (Ach.) Räs in An. Soc. Scient. arg. Secc. S Fe 131: 103 (1941).

Xanthoria parietina var *ectanea* (Ach.) Kickx, in Flore Cryptog. Flandres, 2: 228 (1867).

Parmelia parietina var *ectanea* Ach. in Lichen. Univ. 464 (1810).

Locally abundant on limestone close to the sea and on bark and dead wood of coastal shrubs. Cape Peron South, on limestone (UWA 665, UWA 667, UWA 789); Garden I., at South West Point (UWA 1039); Rottneest I., abundant on indurated limestone about the salt lakes (UWA 1090); North Beach, on dead wood (UWA 715).

Xanthoria parietina (L.) Beltr. in Lichen. Bassan. 102 (1858).

Lichen parietinus L. in Sp. Pl. 1143 (1753).

Occasional on limestone near the sea but more frequent on dead wood and bark of coastal shrubs. North Beach, on bark (UWA 694); Rottneest I., on dead wood (UWA 308); Garden I., on bark (UWA 236).

Buelliaceae

Buellia alboatra (Hoffm.) Branth. and Rostr., in Botan. Tidskrift, IV: 239 (1869).

Verrucaria alboatra Hoffm. Descript et Adumbr., Plant Lich. I, 76, tab. XV (1790), fig. 2 et Deutschl. Flora 193 (1796).

Lichen alboater Hoffm. Enum. Lich. 30 (1784).

Common on limestone close to the sea, becoming less abundant inland. North Beach (UWA 792); Cape Peron South (UWA 790); Garden I., at Beacon Head and elsewhere on limestone (UWA 1038, UWA 1042); Rottneest I., abundant on travertine limestone about the salt lakes (UWA 1094, UWA 1091); Point Roe in the Swan River Estuary (UWA 791, UWA 794); Point Mount Henry on the Canning River Estuary (UWA 605, UWA 609, UWA 612, UWA 791, UWA 794).

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7.—New information about the Quaternary distribution of the thylacine (Marsupialia, Thylacinidae) in Australia

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Abstract

Thylacine remains and associated faunas are reported from cave deposits in the Kimberley Division, the South West Division and the Hampton Tableland of the Eucla Division of Western Australia. The thylacine remains from the Kimberly Region are the first reported from northern Australia. Bone from the same deposit in the Kimberley Region is radiocarbon dated at 0 ± 80 years B.P. (GaK-3890). This date may not apply to the thylacine remains in the deposit. The deposit from the South West Division contains thylacine remains which have been radiocarbon dated at 3090 ± 90 years B.P. (ANU-716). These are the youngest reported from the South West Division. The deposit from the Hampton Tableland and other published faunas (e.g., Wakefield 1964) provide evidence for considering that of several possible causes for the thylacine's decline, the most likely is competition with the introduced eutherian dog.

Introduction

Thylacinus cynocephalus has been reported from Quaternary deposits in New Guinea and all states of Australia except the Northern Territory (e.g. Van Deusen 1963, Partridge 1967, De Vis 1894, MacIntosh and Mahoney 1964, Gill 1953). It has never been positively recorded living within historic time from any area except Tasmania, although there are many records of sightings of thylacine—like animals unsupported by material evidence. Thylacines may still be living in certain remote areas of Tasmania but the last living individual captured in the wild was at Mawbanna in 1930 (Marlow 1968).

The most recent published dates for Australian mainland occurrences of thylacines are those recorded by Lawton and Twidale (1964) as between 3240 ± 80 and 3881 ± 85 radiocarbon years B.P. and by Partridge (1967) as 3280 ± 90 radiocarbon years B.P.

The taxonomy used in this paper is that adopted by Ride (1970). Catalogue numbers refer to specimens in the collections of the Western Australian Museum. Certain caves are listed with registration numbers given by the Western Australian Speleological Group (pers. com. Mr. P. J. Bridge). Western Australian cave names are given without the possessive "s" in accord with the policy of the Lands and Surveys Department of Western Australia (e.g. Murray's Cave becomes Murray Cave).

The Kimberley Division

In 1970, Dr. R. E. Lemely, Mr. A. M. Douglas and the author collected bones and other remains within 11 cm of the surface of a small limestone pocket referred to by us as the "Tunnel Creek Carnivore Lair" in the wall of a collapsed doline, above Tunnel Creek in the Napier Range, of the southwestern Kimberley Division. The remains have been registered in the collections of the Western Australian Museum as 71.12.60 - 71.12.119.

The fauna includes the following taxa:

	Metatheria
Dasyuridae	<i>Phascogale</i> cf. <i>P. tapoatafa</i> <i>Antechinus</i> cf. <i>A. macdonnellensis</i> <i>Dasyurus hallucatus</i>
Thylacinidae	<i>Thylacinus</i> sp. (see Ride 1964 and Archer 1972 for comments about species)*
Peramelidae	<i>Isoodon</i> sp.* <i>Macrotis lagotis</i>
Phalangeridae	<i>Trichosurus</i> sp. or <i>Wyulda</i> sp.*
Petauridae	<i>Petropseudes dahli</i>
Macropodidae	<i>Peradorcas concinna</i> <i>Petrogale</i> cf. <i>P. brachyotis</i> <i>Megaleia rufa</i> *
	Eutheria
Muridae	<i>Pseudomys nanus</i> <i>P. forresti</i> <i>Zyzomys argurus</i> <i>Conilurus</i> cf. <i>C. penicillatus</i> * <i>Mesembryomys</i> cf. <i>M. macrurus</i> <i>Rattus tunneyi</i>
Pteropodidae	<i>Pteropus</i> sp.*
Vespertilionidae	small bat (indet)
Megadermatidae	<i>Macroderma gigas</i>

* The specimens representing these taxa probably do not represent undescribed species. They were not specifically identified either because the material is post-cranial in nature (e.g., the thylacine specimen is a humerus, Fig. 1) or the described species of the taxa could not be adequately differentiated using only the characters present in the fossil specimens.

Non-mammal remains include two species of lizards, at least one species of snake, a catfish spine and fish vertebrate, fresh-water crabs, mussels, terrestrial snails, insects and spiders.

The specimens from this deposit representing *Macrotis lagotis*, *Petropseudes dahli*, *Peradorcas concinna* and *Conilurus penicillatus* represent range extensions for these species within the Kimberley region of Western Australia (Ride 1970). *Pseudomys forresti* has not previously been recorded from the Kimberley region.

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Figure 1.—The proximal portion of a thylacine humerus (71.12.119) from the Kimberley deposit. It is compared with the proximal end of a thylacine humerus (Geological Survey of Western Australia Number F6353) from a cave on the Hampton Tableland of the Eucla Basin of Western Australia. There is also a distal portion of a thylacine humerus (perhaps the same humerus) from the Kimberley deposit.

The vertebrate remains in the deposit probably represent a carnivore's accumulation. The larger species of marsupials are represented mainly by juvenile specimens. It is not uncommon behaviour for some "scavenger-predators" to specialize on juvenile as well as senile and sick individuals of larger prey species (Estes 1967). In addition the animals present in the deposit, such as the crabs, fresh-water mussels, arboreal *Phascogale* sp., and plains-dwelling *Megalia rufa* represent such diverse habitats that it is highly unlikely that their remains could have accumulated in one place without the assistance of some transporting agent. Because the limestone pocket is horizontal, shows no evidence of flooding, and has no entrances from above, contribution to the deposit by means of floods or animals dropping in from above seems improbable. It is most likely that some animal with catholic food habits accumulated the remains in one place.

The presence of the mussel shells and perhaps also the crab and fish remains suggest Aboriginal man may have been involved. He would

certainly be able to procure mussels and crabs from the wet sand of Tunnel Creek. However, it is also possible that dogs or thylacines might be able to do the same thing. It may be significant that no burned bones or stone artifacts were recovered from the deposit. The "Tunnel Creek Carnivore Lair" limestone pocket is floored with irregular stones which made it very uncomfortable to sit or recline while trying to reach bone material on the surface which lay under low ledges at the margins as well as in the centre of the pocket. This suggests that Aborigines might not use the small pocket as a shelter.

Although Aborigines might have tossed things into this pocket, the absence of burned bones and artifacts suggests that the animal material was gathered by a non-human carnivore.

Much of the bone from this deposit is broken. The manner in which bone is broken often suggests which carnivore or other agency is responsible (e.g. Brain 1967, Douglas, Kendrick and Merrilees 1966, Lundelius 1966). The bone from the "Tunnell Creek Carnivore Lair" is not as

thoroughly smashed as bone from certain undoubted archaeological deposits (e.g. Puntatjarpa, in the Warburton Range of Western Australia, report in press). On the other hand, Douglas, Kendrick and Merrilees (1966) have demonstrated the type of bone-breakage caused by *Sarcophilus harrisii* in which Bettong-sized and smaller animals are broken up into small pieces in a manner similar to bone broken by humans. The bones from the "Tunnel Creek Carnivore Lair" are not as thoroughly broken as this and may represent the activities of dogs or thylacines.

Bone fragments from the sample collected were submitted for radiocarbon dating. The result (Gak-3890) was 0 ± 80 radiocarbon years. It should be pointed out that because of variations in atmospheric C^{14} concentrations, this date might represent about 200 calendar years (Radiocarbon 1966). Other uncertainties and variables affecting the reliability of such young dates are given in Polach and Golson (1966). Because the thylacine remains consist of only a broken humerus, the thylacine bone itself was not submitted as part of the radiocarbon sample. It is possible that the age of the thylacine bone differs from the age of the bone in the sample submitted for dating. The thylacine humerus is not as fresh-looking as some of the other bone in the sample. The possible difference in age of the various bones in the deposit cannot be determined.

Brandl (1972) reports Aboriginal rock-paintings in Arnhem Land of a striped animal which he interprets as possibly representing *Thylacinus*. This interpretation is convincing. Although the thylacine bone from the "Tunnel Creek Carnivore Lair" deposit reported here may not be the same age as the other bone in the deposit, these Arnhem Land rock-paintings reported by Brandl (1972) would seem to add support to the idea that thylacines may have survived in northern Australia until late recent time.

Wright (1968) reports rock art from the Pilbara Region of northwest Australia which he considers represents a dog-like mammal with vertical stripes and other features suggesting a thylacine.

The Pilbara Region is intermediate between the Kimberley area and the South West Division in Western Australia.

The South West Division

Excavation by Mr. I. Murray, Miss E. A. Jefferys and the author in a stratified deposit in Murray Cave (Yn52), formed in what is commonly referred to as "Coastal Limestone" (Smith 1963) about 40 km north of Perth recovered a fauna that included *Thylacinus cynocephalus* (to be reported fully elsewhere). Remains of thylacines (e.g. 72.1.1148) were collected from the surface of the cave floor and between the surface and 7 cm in the excavated deposit. A radiocarbon date (ANU-716) on charcoal from 1-7 cm is $3\,090 \pm 90$ radiocarbon years B.P. This is the youngest dated occurrence of thylacines

from the South West Division of Western Australia. *Thylacinus cynocephalus* is recorded from the Mammoth Cave fauna which may be older than 31 500 years B.P. (Merrilees 1968). This is the only other dated occurrence of thylacines from the South West Division although they are not uncommon in deposits of this area particularly in the Cape Leeuwin—Cape Naturaliste region (Merrilees 1968).

The Murray Cave fauna includes the following species (specimens registered as 72.1.1148-72.1.1170):

	Metatheria
Dasyuridae	<i>Antechinus apicalis</i> <i>Antechinus flavipes</i> <i>Dasyurus geoffroi</i> <i>Sarcophilus harrisii</i>
Thylacinidae	<i>Thylacinus cynocephalus</i>
Peramelidae	<i>Isodon sp.*</i>
Phalangeridae	<i>Trichosurus vulpecula</i>
Petauridae	<i>Pseudocheirus peregrinus</i>
Macropodidae	<i>Bettongia lesueur</i> <i>B. penicillata</i> <i>Macropus irma</i> <i>M. eugenii</i> <i>Petrogale penicillata</i> <i>Setonix brachyurus</i>
	Eutheria
Vespertilionidae	(indet)*
Megadermatidae	<i>Macroderma gigas</i>
Muridae	<i>Rattus fuscipes</i> <i>pseudomyine</i> (indet)*

* See note at bottom of the "Tunnel Creek Carnivore Lair" list above. In addition there is at least one species of lizard, one species of frog and three species of terrestrial snails.

The bone material from Murray Cave is considered to represent a carnivore's accumulation. As in the "Tunnel Creek Carnivore Lair" deposit reported above, the larger species are mainly represented by specimens of juvenile individuals. It differs from the "Tunnel Creek Carnivore Lair" deposit in that almost every bit of bone is broken into much smaller pieces, including most of the jaws. Bone destruction of this sort is typical of *Sarcophilus harrisii* (Douglas, Kendrick and Merrilees 1966).

One of the individuals of *Thylacinus cynocephalus* from Murray Cave consist of a maxilla and dentary representing a very small pouch-young thylacine (Fig. 2). The roots of the crowns had not yet formed and the teeth are stacked in overlapping positions in the dentary. There is little doubt that this animal was taken into Murray Cave, either by or with its mother, or by a predator.

The Hampton Tableland of the Eucla Division

In 1969 and 1970 Messers B. Muir, K. Akerman, and others accompanied the author to Horseshoe Cave (N59) northeast of Madura on the Hampton Table and where three excavations were dug and a large fauna recovered (to be fully reported elsewhere). This fauna included

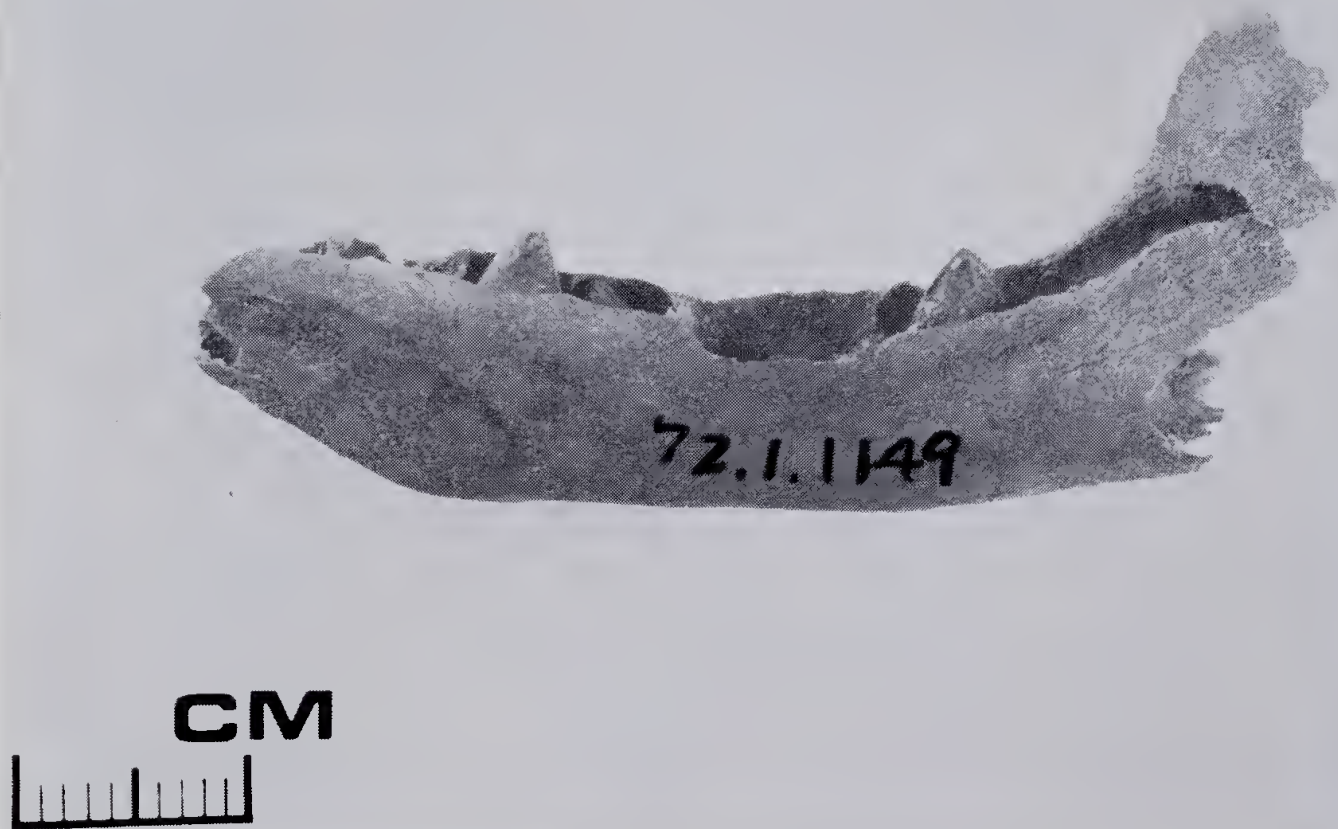


Figure 2 —The Murray Cave juvenile thylacine specimen (72.1.1149). The teeth probably would not have pierced the gum at this stage of dental development and the animal would have been totally dependent on its mother.

Thylacinus cynocephalus. Specimens (registered as 72.1.1-72.1.1000 etc.) from the same deposit represent the following species:

	Metatheria	Muridae	Eutheria
Dasyuridae	<i>Sminthopsis crassicaudata</i> <i>Sminthopsis murina</i> <i>Antechinomys spenceri</i> <i>Phascogale calura</i> <i>Dasymercus cristicauda</i> <i>Sarcophilus harrisi</i> <i>Dasyurus</i> cf. <i>D. geoffroi</i>		<i>Pseudomys</i> cf. <i>P. gouldii</i> <i>P. occidentalis</i> <i>P. desertor</i> <i>P. hermannsburgensis</i> <i>Leporillus apicalis</i> <i>L. conditor</i> <i>Notomys cervinus</i> (and probably other species of the genus) <i>Rattus</i> cf. <i>R. villosissimus</i>
Thylacinidae	<i>Thylacinus cynocephalus</i>	Hominidae	<i>Homo sapiens</i>
Peramelidae	<i>Perameles</i> cf. <i>P. bougainville</i> <i>Chaeropus ecaudatus</i> <i>Isodon obesulus</i> <i>Macrotis lagotis</i>	Canidae	<i>Canis familiaris</i>
Phalangeridae	<i>Trichosurus vulpecula</i>	Vespertilionidae	Small bats (indet)*
Burramyidae	<i>Cercartetus</i> cf. <i>C. concinnus</i>		
Vombatidae	<i>Lasiorhinus latifrons</i>		
Macropodidae	<i>Caloprymnus campestris</i> <i>Bettongia lesueur</i> <i>B. penicillata</i> <i>Onychogalea lunata</i> <i>Lagorchestes</i> cf. <i>L. hirsutus</i> <i>Lagostrophus fasciatus</i> <i>Petrogale</i> sp. <i>Macgaleia rufa</i>		

* See note at the bottom of the "Tunnel Creek Lair" list above.

Sminthopsis murina, *Pseudomys* cf. *P. gouldii*, *P. desertor*, and *Rattus* cf. *R. villosissimus* have not previously been recorded from the Hampton Tableland.

Thylacine remains have been reported from the Hampton Tableland (e.g. Partridge 1967, Lowry and Merrilees 1969). A date of 3280 ± 80 radiocarbon years reported by Partridge (1967), was based on dried flesh from a thylacine found on the surface of Murra-el-elevyn cave. Dates of 4650 ± 104 , 4550 ± 112 and 4650 ± 153 radiocarbon years B.P. are reported by Lowry and

Table 1

Thylacine and dog remains from trench excavations in Horseshoe Cave (N59).

T=thylacine, D=dog. There are also dog remains on the surface of the cave floor. The synopsis column gives a summary of the dog, thylacine and relevant dates from particular trench excavations (no. in parenthesis).

Depth (cm)	Trench 1	Depth (cm)	Trench 2	Depth (cm)	Trench 3	Synopsis
				30-40	D (e.g. 72.1.691)	D on surface D 30-40 (3)
90-100	T (e.g. 72.1.155)	40-50 50-53	T (e.g. 72.1.482) T (e.g. 72.1.512) (date from 50-53 level: 7030 ± 130, GaK-3888, bone)	50-60	3570 ± 100 (GaK-3570, bone) and 4500 ± 330 (GaK-3476, charcoal)	4500 ± 330 (3) T 90-100 (1)
110-120	5630 ± 120 (GaK-3814, bone)					5630 ± 120 (1)
200-220	T (e.g. 72.1.307)					T 200-220 (1)
250-260	15800 ± 1800 (GaK-3815, bone)					15800 ± 1800 (1)

Merrilees (1969) for a thylacine mummy from the surface of Thylacine Hole cave. Thylacine remains from Horseshoe Cave (N59) are summarized in Table 1 with radiocarbon dates and the stratigraphic levels containing dog remains. The specimen (72.1.512) from the Trench 2 level dated at 7030 ± 130 radiocarbon years B.P. is the oldest dated thylacine from the Hampton Tableland. The specimen (72.1.307) from the Trench 1 200-220 cm level may represent an even older thylacine.

Discussion

It is now clear that during Quarternary time, thylacines existed throughout the Australian continent, as well as in New Guinea and Tasmania. However, the reasons for the decline of the thylacine are not clear. Fleay (1946) believes that snares and baits laid by European hunters were the cause for the decline of Tasmanian thylacines. Merrilees (1968) and Jones (1968) suggests that Aborigines may have played a major role in the extinction of some of Australia's Quaternary marsupials. Troughton (1967) and Jones (1970) suggest that competition with dogs may have been a major reason for the decline of the thylacine.

Although thylacine remains have occasionally been recovered from excavations that contain Aboriginal remains or artifacts (e.g. Fromm's Landing, MacIntosh and Mahony 1964, Horseshoe Cave reported in this paper) there is no evidence (such as burned thylacine bones in midden deposits) to suggest Aborigines actively hunted thylacines. Aboriginal man might have been responsible for destroying such vital aspect of the thylacine's habitat such as the vegetation or food supply. But the fact that thylacines and Aborigines persisted together into historic times in Tasmania suggests co-existence could have also taken place on the mainland. Wright (1971) presented evidence for Aboriginal activity in Koonalda Cave on the Hampton Tableland of the Nullarbor. He states (p. 28) that "...traces of human activity are present from roughly 22 000-15 000 years ago". Considering the date of 3280 ± 80 radiocarbon years B.P. recorded by Partridge (1967) for thylacine remains in Mura-el-elevyn Cave on the Hampton Tableland,

thylacines and Aborigines probably co-existed on the Hampton Tableland for at least 18 000 radiocarbon years. Therefore Aborigines were probably not responsible for the decline of the thylacine on the Australian mainland or Tasmania.

Dogs and thylacines

Tindale (1959) suggests that dogs were originally brought into Australia by Aborigines. The oldest known dog remains in Australia are from a cave at Mt. Burr in South Australia, and are dated at between 7450 ± 270 and 8600 ± 300 radiocarbon years B.P. (Mulvaney 1969). Dogs occur in New Guinea (Troughton 1971), formerly occurred in New Zealand (Allo 1971) but are not known to have occurred in Tasmania prior to the arrival of Europeans around 1798 (Jones 1970). Jones (1968) suggests that Tasmania has been separated from the Australian mainland for about 12 000 years and that therefore (p. 258) it "...seems highly likely that the dingo first appeared in Australia after about 12 000 years ago, and in view of the Mt. Burr evidence some time before 7 000 years ago". Merrilees (1968) has suggested that a dog tooth in the Western Australian Museum collections from the Mammoth Cave deposit probably did not come from the Pleistocene deposit in that cave (which is dated at greater than 31 000 and 37 000 radiocarbon years B.P.) and Jones (1970) states (p. 258) that "Claims for dog teeth in Pleistocene (Australian) deposits have not been confirmed".

Thylacine remains are known from Australian, Tasmanian and New Guinean late Quaternary deposits (Merrilees 1968, Van Deusen 1963, Gill 1963, Gill and Banks 1956) and may have been sympatric with dogs that occurred in New Guinea and Australia. Actual instances of the sympatric occurrence of the two species interpretable from fossil deposits in Australia have not been clearly demonstrated. At present the only instance known to me is that recorded by Wakefield (1967). He reports dog and thylacine remains from the same "Recent" layer in the McEachern's Cave in southwest Victoria. This layer is 14 inches thick. Wakefield (1967) also reports dog and thylacine remains from a

"mixed" sand at depth of 14 to 30 inches. It is possible that this report indicates the two species were sympatric.

On the other hand there are several deposits in which large excavations have revealed superposition of dog remains over those of thylacines (e.g. Wakefield in Mulvaney, Lawton and Twidale 1964). In Horseshoe Cave (reported in this paper and by Archer 1972) on the Hampton Tableland dog remains occur in two of the three excavated trenches but only at levels above levels containing thylacine remains (see above). Lowry and Merrilees (1969) report a radiocarbon date of 220 ± 96 years B.P. for a desiccated carcase of a dog from another cave on the Hampton Tableland. This date is younger than any that applies to thylacine remains in Australia. In fact I am unaware of any radiocarbon dated sequences in Australia which demonstrate an example of superpositional relationship of thylacine over dog remains. It is possible that the thylacine remains reported in this paper from the "Tunnel Creek Carnivore Lair" Kimberley deposit are contemporaneous with the fauna which has been radiocarbon dated at 0 ± 80 years B.P. (see above). If this is the case it is most likely that dogs and thylacines have been sympatric in northern Australia for some unknown time. But considering that the thylacine remains in this Kimberley deposit are (as noted above) somewhat differently preserved from the other bones in the deposit, it cannot be argued on the evidence of this deposit alone that thylacines were sympatric with dogs in northern Australia.

What little is known of New Guinean thylacine and dog history suggests a similar situation. White (1971) suggests (p. 190) that dog remains are found in New Guinea shelter sites "...only in very recent times...". On the other hand thylacine remains have been recorded by Van Deusen (1963) from the Kiowa Rock Shelter in New Guinea above a level dated at $9\,920 \pm 200$ years B.P. (Bulmer 1964 and Van Deusen pers. com.).

Tasmanian thylacines are reputed (e.g. Troughton 1967) to have eaten wallabies, smaller marsupials, rats, birds, probably echidnas and possibly lizards as natural foods. Rolls (1969) records (p. 361) that following an active and successful campaign to reduce the numbers of wild dogs (dingo) in southeast Australia in 1863 "...there began a startling build-up of wildlife. Kangaroos, wallabies, pademelons, rat-kangaroos, bilbies, and bandicoots which had all been present in insignificant numbers sprang up like grass". Although it is possible that factors other than the reduction of dog numbers might have contributed to this resurgence of wildlife, it would seem probable that dogs could usurp the thylacine's natural foods in areas where the two carnivores were sympatric. Calaby (1971) says (p. 90) of the introduced dog that it "...is an opportunist predator with a catholic diet including virtually anything it can catch, vertebrate or invertebrate, together with carrion and even some vegetable material". I have recently examined stomach contents of dogs trapped in

northwestern Western Australia (by courtesy of Mr. Simon Whitehouse) and identified specimens of feral cats (*Felis domesticus*) in two stomachs. It is therefore not unlikely that dogs might even have preyed directly on thylacines if given the opportunity. The dog and thylacine are of comparable size and partitioning of the habitat without a long historical basis, probably would not have occurred.

Further evidence for competition between dogs and thylacines comes from a consideration of the Tasmanian situation. Dogs are not known to have been present in Tasmania prior to historic times (Jones 1968). Thylacines on the other hand persisted in Tasmania despite the presence of Aborigines (see above). It could be argued that the introduction of dogs into Tasmania in historic times was a significant reason for the eventual decline of the thylacine in Tasmania. Guiler (1961) examined records of thylacine kills by European hunters in Tasmania. He noted that the number of thylacines killed remained relatively constant in two areas where killing for bounties had begun in 1888, until the sudden general decline throughout Tasmania around 1909, rather than gradually declining in those areas. He concluded that for this reason hunting by Europeans was not the sole cause of the thylacine's decline. He suggested disease might have been a factor in causing the decline. The same argument could be used to suggest that no single gradual pressure, including pressures caused by the introduced dog, brought about the Tasmanian thylacine's decline. Guiler (1961) did not however consider that predation by Europeans (and or competition with the dog during historic times) may have been responsible for lowering the thylacine populations in Tasmania to a critical level at which disease or some other factor could have dealt a crushing blow. It would seem too much of a coincidence that the Tasmanian thylacine population declined so drastically for unknown reasons during the only 11 year period of Quaternary time when it was also actively and methodically predated upon by human hunters. Whatever the cause for Tasmanian thylacine decline, the fact that thylacines existed in Tasmania into historic times and evidently did not on the Australian mainland, suggests that dogs may have been the significant factor which brought about the decline of the thylacine on the Australian mainland.

There would appear to be no comparable situation within recent time involving introduced dogs and indigenous dog-sized, non-canid carnivores on any other continent. Dog-sized canids are indigenous to Africa, e.g. jackals, *Canis adustus*, bush dogs, *Lycyon pictus*, South America (bush dogs, *Speleothos* spp., maned wolves, *Chrysocyon* sp. etc.), and North America, Europe and Asia (grey wolves, *Canis lupus*). On the other hand a similar situation occurred in South America during late Pliocene (Montehermosan) time. In South America the only large carnivores were the marsupial borhyaenids which included thylacine-like and thylacine-sized animals. When faunal interchange became possible

across Panama, canids, procyonids, ursids, mustelids and felids entered South America and successfully colonized the continent, whereas the borhyaenids became extinct (Patterson and Pascual 1968). It is probably not possible to know what particular role the canids had in displacing the borhyaenids.

Colbert (1955) suggests that marsupials are "second-class mammals" as compared with eutherians. This impression arises as a result of the apparent competitive inferiority exhibited by many marsupial groups. Storr (1958) has argued that this is because most marsupials evolved in isolation on southern continents. They were not subjected to the constant testing that Holarctic eutherians underwent. Thylacines were in this sense at a disadvantage in a confrontation with the dog. The modern dog is a representative of a stock of eutherians that had already successfully confronted the South American marsupial borhyaenids. The Australian thylacine probably had even less of a chance for survival against such a seasoned competitor than the South American Borhyaenids.

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8.—Petrology of chert artifacts from Devils Lair, Western Australia

by J. E. Glover¹

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Abstract

Fossiliferous chert artifacts from Devils Lair, a small cave in the Cape Leeuwin-Cape Naturaliste region, Western Australia, consist of silicified limestone (biomicrite) containing a little glauconite. Specimens examined in thin section came from deposits ranging in age from ca 12 000 years B.P. to more than 17 000 years B.P. They resemble fossiliferous Eocene chert from surface and near-surface sites in the Perth Basin, and are probably derived from the same formation.

Introduction

Flakes of chert and quartzite worked by aborigines have been found at many sites in and just outside the region of the Perth Basin, and form abundant components of surface or near-surface accumulations. Other utilized rock and mineral flakes, including dolerite, granite, silcrete, quartz, schist and K-feldspar are com-

monly present as minor constituents. Chopping and grinding tools, generally of dolerite or quartzite, are found in a few places. Some of the chert is unfossiliferous and of probable Precambrian age, but most of it is bryozoan chert of Eocene age (Glover & Cockbain 1971).

This paper describes the petrology of some chert flakes excavated from the Devils Lair cave outside the Perth Basin, and compares it with the petrology of flakes from surface scatters within the region of the basin.

Location and age of the artifacts

Devils Lair is a small cave in Quaternary limestone (the "Coastal Limestone") on the Precambrian Leeuwin Block (Fig. 1) and it contains a deep deposit with abundant bone fragments and some stone artifacts (Dortch & Merrilees 1971, 1973). The artifact material includes chert (five individual specimens of which are described herein), quartz (*e.g.* B1558), calcrete

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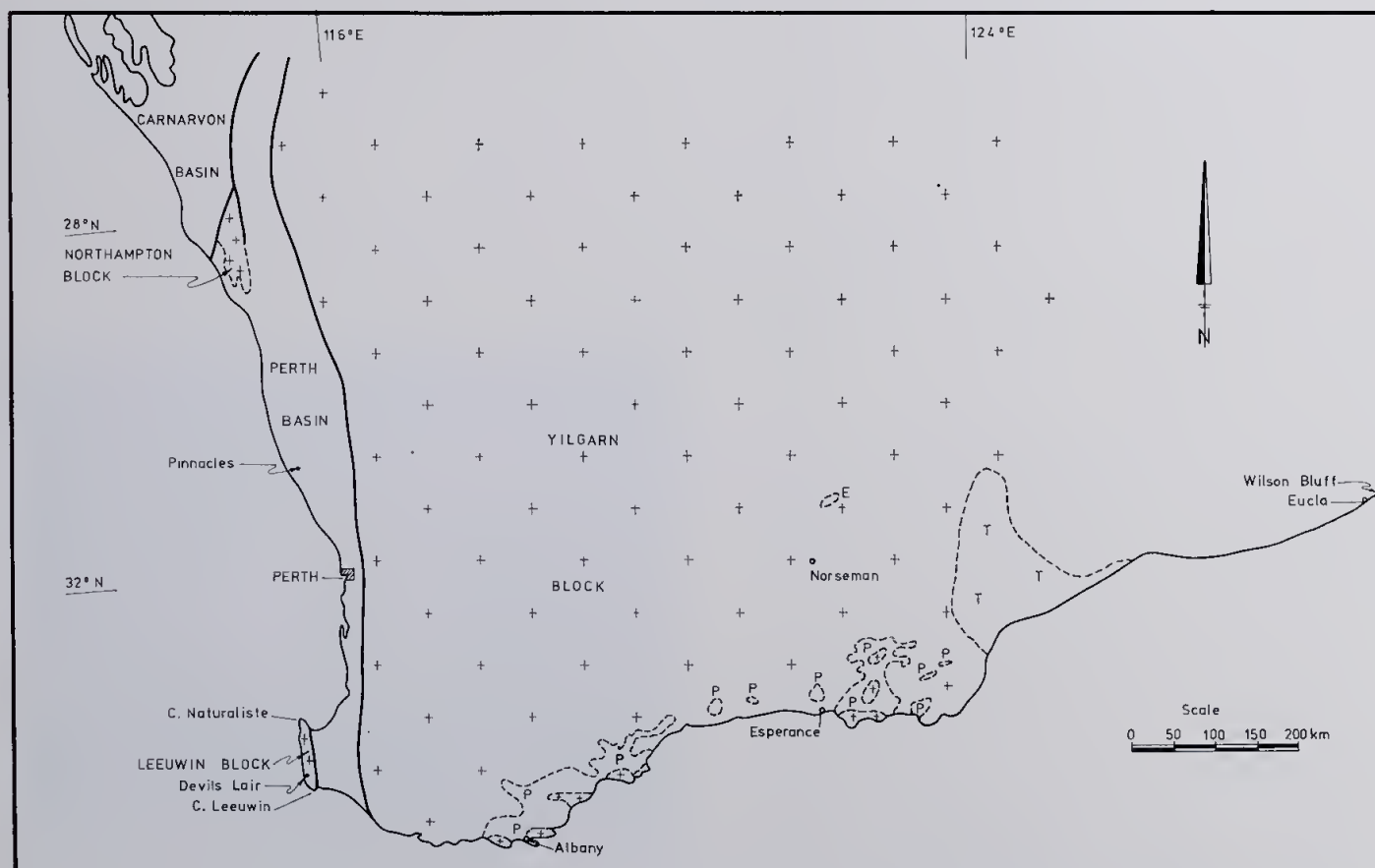


Figure 1.—Locality map of southwestern Western Australia. Precambrian indicated by crosses. Eocene units as follows: P = Plantagenet Group, E = Eundynie Group, T = Toolinna Limestone. All artifacts mentioned in the text, except those from Devils Lair and the Pinnacles area, come from in or near the Perth metropolitan area.

(e.g. B1537) and bone (e.g. B1573). Mr. C. E. Dortch, Western Australian Museum, gave the following information about the locality of the chert specimens examined, and the age of the strata from which they were taken:

Specimen	Trench	Estimated age in years B.P.
A22013	1A	Probably ca 12 000
B1513	5	ca 12 000
B1520	5	ca 14 000
A21972	1A	over 12 000
B1586	6	over 17 000

He also states (C.E. Dortch, *pers. comm.*) "Other artifacts from Devils Lair range in estimated age from less than 12 000 to more than 24 000 years old, but no chert is known at present older than about 19 000 years".

Petrology of the Devils Lair chert

Despite superficial differences in colour and opacity, the flakes are sufficiently alike in hand specimen and thin section to be described together.

Individual flakes are not uniformly coloured, but range from off-white through grey to grey-brown. Specimen A22013 ranges from off-white to brown, and is different from the other flakes in that the brown portions are vitreous rather than dull, and are very faintly translucent. The flakes have a conchoidal fracture except for the off-white parts which have an uneven fracture and can be scratched with a knife. Minute organic fragments can be detected with the hand lens. No effervescence was observed when dilute hydrochloric acid was applied to the surface of the flakes, despite the observed presence of calcite under the microscope (see below). This is probably partly because the carbonate is generally well protected by surrounding silica, and partly because the acid tends to be absorbed in the softer, off-white portions, which are porous. An X-ray powder pattern of specimen B1513 confirms the presence of calcite, but shows no dolomite.

Under the microscope the flakes are seen to consist mainly (70-85%) of a mixture of cryptocrystalline to microcrystalline silica, and coarser, commonly spherulitic, chalcedony. A variable but significant proportion (10-25%) consists of calcite, and other minerals include limonite-impregnated clay, rare silty quartz, pellets of green to brown glauconite up to 0.1 mm in diameter, and some black opaque material that is probably carbonaceous.

The calcite forms irregularly-shaped patches, or assumes the outline of fossil fragments. Most fossils have been at least partly silicified, and many are now composed entirely of silica (see Figs. 2, 3 and 4). Remains include multi-rayed calcareous spicules, foraminifers (apparently planktonic), small bivalve fragments, and bryozoans. One calcite fragment with unit extinction that is probably an echinoderm plate was seen. In addition, there are minute non-calcareous objects, too small for satisfactory



Figure 2.—B1520. Small, thin-walled bivalve in chert. The walls are still largely carbonate, but the infilled material is cryptocrystalline silica and chalcedony. University Geology Department Neg. P2665. X 30. Crossed polarizers.

observation in thin section, that may be organic.

The fabric indicates that the rocks before silicification consisted essentially of fossil fragments in a matrix of finely divided carbonate, and they would therefore have been biomicrites in the terminology of Folk (1962).

Comparison with other fossiliferous chert flakes

The fossiliferous chert from Devils Lair was compared in hand specimen and thin section with fossiliferous chert from surface sites near Abernethy Road (Kewdale), Bibra Lake, Monagers Lake, Lake Gnangara, and the Pinnacles area north-east of Lancelin. The surface material ranges in colour from off-white and grey to yellow-brown, with other minor variations, but the colour differences seem largely superficial, and are apparently due to the effect

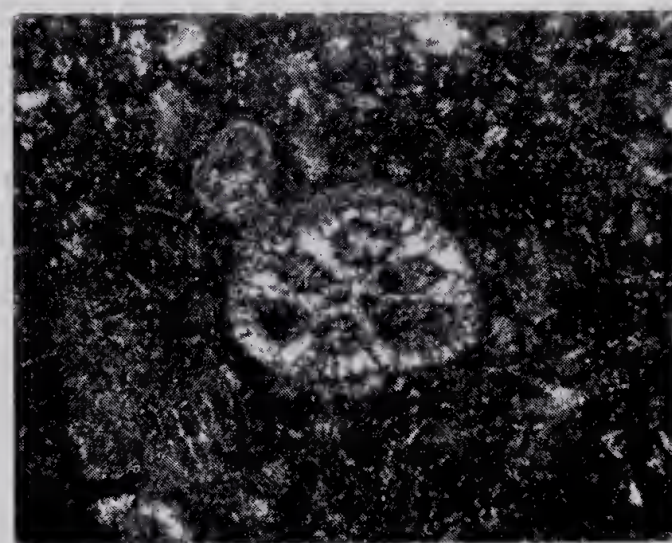


Figure 3.—B1586. Bryozoan in transverse section in chert. The walls have been completely replaced by chalcedony, and the cavities contain opaline and chalcedonic silica. University Geology Department Neg. P2661. X 27. Crossed polarizers.

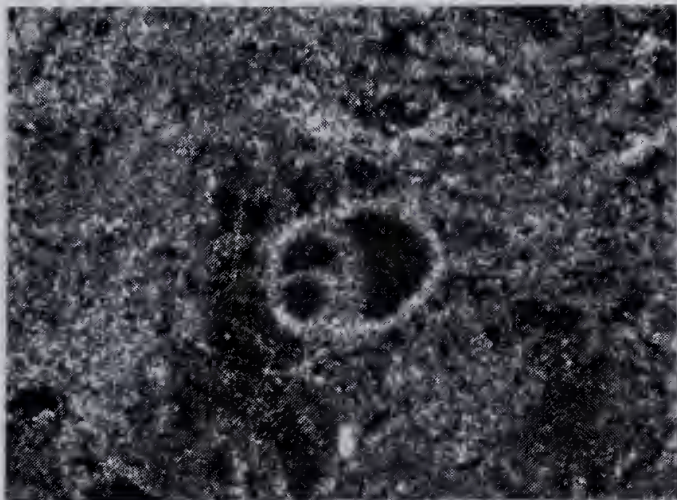


Figure 4.—A21972. Foraminifer in chert. The walls are chalcedonic and the cavities are filled with opal and cryptocrystalline silica. University Geology Department Neg. P2667. X 30. Crossed polarizers.

of the beds in which they are found. As with the Devils Lair chert, all sectioned material consists of silicified biomicrite. The surface material contains less carbonate, and seems generally to have been more completely silicified. Glauconite does not occur in all material, but is present in many Pinnacles flakes.

Origin of the Devils Lair chert

The textural and mineralogical similarities between the chert from Devils Lair and from surface scatters in the Perth Basin are strong, and suggest that all have been derived from the same formation. A few large fragments of surface material are about 10 cm long in their greatest extension, and their appearance is consistent with derivation from chert nodules or irregularly silicified beds in limestone. Nothing, however, can be added at present to earlier speculation (Glover & Cockbain 1971) about a possible western source now off-shore, or an eastern or southeastern source in Eocene formations on the Yilgarn Block.

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9.—The development of the cheek-teeth in *Antechinus flavipes* (Marsupialia, Dasyuridae)

by Michael Archer¹

Manuscript received 20 March, 1973; accepted 19 March, 1974.

Abstract

The ontogenetic development of the cheek-teeth in a developmental series of 14 pouched young of *A. flavipes* is described. There were found to be eight post-canine tooth families each of which produces only one tooth, or generation: P1, P3, P4, dP4, M1, M2, M3, M4. The canine family has two generations. The development of the upper and lower laminae differ in the posterior region probably because of the crowding effect in the mandible caused by the ascending ramus. The time of initiation of all teeth is consistent with an interpretation described by Woerdman (1921) as *Zahnreihen*. In *A. flavipes* there appear to be two *Zahnreihen* along the length of the cheek-tooth row. One is initiated at the C position and the other at the dP4 position. The molariform cheek-tooth series, the dP4-M4, represent one series of related teeth, and the C-P4 represent a second set of related cheek-teeth. The traditional definitions of premolars and molars do not apply to cheek-teeth of *A. flavipes* and if the situation that exists in this species is found to be more general among the marsupials, a more appropriate series of definitions and nomenclature may be required to differentiate the cheek-teeth.

Introduction

Numerous attempts have been made by research workers to establish a basis for identifying homologous teeth in metatherians (marsupials) and eutherians. The most commonly used basis is the phenomenon of tooth replacement. Owen (1840-5) established the basic principle that premolars were post-canine teeth which had milk predecessors. Molars were post-premolar teeth which had no milk predecessors. Accordingly, eutherians are considered to have four premolars and three molars. Metatherians, which presumably have a common ancestry with eutherians, have three premolars and four molars. Consequently it appears that metatherians have lost one premolar and gained or retained an additional molar. An alternative is that the first molar of metatherians is actually a molariform premolar. Differences in opinion about which premolar has been lost (if in fact any have been lost) have produced conflicting systems of dental terminology.

Embryological investigations have often tended only to confuse the issue. As a result of some of the earlier embryological studies, the question of the homology of the whole tooth row was raised and has been the cause of further conflicting terminologies. Most embryological investigations were, however, carried out on material inadequate to clarify the questions of premolar

and molar homology. Either the studies have been based on too few or too late developmental stages (e.g. Wilson & Hill 1897, Fosse & Risnes 1972a and b), or upon excellent material of species which have incomplete series of teeth due to phylogenetic reduction (e.g. the macropodids as studied by Berkovitz 1966, and Kirkpatrick 1969, or phalangerids studied by Berkovitz 1968).

The work reported here was based on a good series of pouch young of *Antechinus flavipes* whose adult cheek-tooth dentition contains the maximum number of teeth known in any metatherian except *Myrmecobius* which appears to develop supernumary teeth of very uncertain homology; some Cretaceous *Didelphodon*, Clemens 1966, which may have had four premolars; and possibly *Garzonia*, a specimen noted by Sinclair (1906) having nine antemolar teeth of uncertain homology.

The teeth of vertebrates are basically ectodermal structures which develop from oral epithelial tissue. In reptiles (Edmund 1960), the oral epithelium invaginates as a band (the dental lamina) into the matrix of the upper and lower jaws. The free edge of the invaginating band is proliferative and sequentially along its length produces swellings which are identified as tooth buds. As these tooth buds organize and develop the tissues which will eventually produce a functional tooth, they appear to move along the buccal side of the dental lamina, in a vertical direction, towards the oral epithelium. This relative movement of the bud and the free edge of the dental lamina is responsible for the re-appearance of the free edge lingual to the established tooth bud. Subsequently, a second swelling may occur on the free edge of the dental lamina in the same position as the first. Such a vertical sequence of one or more tooth buds is referred to as a tooth family. Each bud is referred to as a tooth generation. There may be many tooth families along the dental lamina and a variable number of generations within each. The situation in mammals is basically the same (Ziegler 1972) except that the invaginated dental lamina is less sheet-like in structure, and as a result the terminal swellings occur nearer to the oral epithelium.

The work presented here is an attempt to determine the number of post-canine tooth families, and generations within those families, in the dasyurid marsupial *Antechinus flavipes*. This information is used to clarify the homologies of the cheek-teeth of metatherians.

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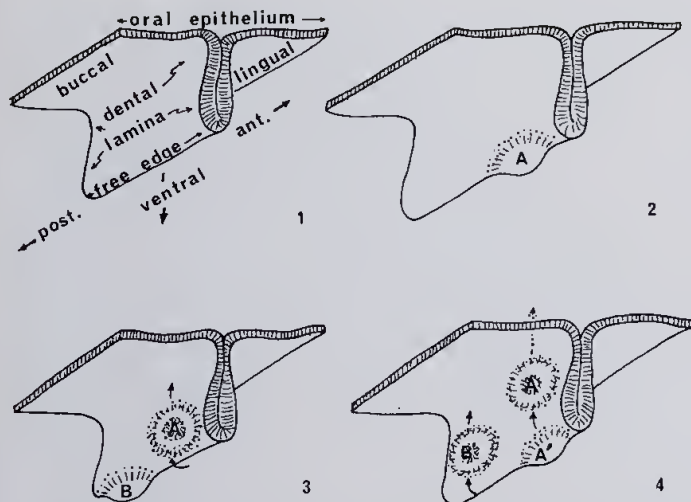


Figure 1.—A schematic and simplified portrayal of the relationship of tooth generations and families to a transected part of the lower dental lamina (modified after Edmund 1960).

1. The dental lamina as an ingrowth of oral epithelium.
2. A terminal swelling (A) of the dental lamina indicating the initiation of a tooth.
3. The tooth (A) appears to rise on the buccal side of the dental lamina and the free edge becomes visible again. A second tooth (B) is initiated posterior to the first (A), again as a terminal swelling of the free edge of the dental lamina.
4. The first tooth (A) initiated is considerably enlarged and now lies just beneath the oral epithelium through which it will eventually erupt. A second swelling (A) of the free edge of the dental lamina beneath the first tooth (A) establishes a second generation in vertical tooth family A.

Material and methods

Three female *Antechinus flavipes leucogaster* from the Wongong River watershed near Byford, W.A., gave birth in captivity during 1969 and 1970. In 1969 eight pouch young were removed from two females at intervals of 4-11 days. One of these young duplicated a developmental stage. In addition two young were preserved at 83 and 105 days from birth. In 1970, six young were removed at intervals of 5-10 days. The sixteen animals removed represented fifteen developmental stages. All of the young were fixed in neutral formalin. With the exception of the 83 and 105 day animals and the single animal which duplicated a developmental stage, the fixed young were decapitated and the heads decalcified in 5.5% ethylene diamine tetra-acetic acid (E.D.T.A.) solution, doubly-embedded using Peterfi's method, and sectioned transversely at 8U. Sections were stained in haematoxylin and eosin. The animal which duplicated a developmental stage was decapitated. The head was cut sagittally: one half was macerated in KOH and stained in alizarin red S solution (as described in Dawson 1926) and cleared in glycerine; the other half was sectioned sagittally and processed as described above for the transverse sections. Two heads of pouch young of unknown age were sectioned transversely and allocated to the series, on the basis of structural development, to the 60+ day developmental stage.

Results

The basic observations of initiation, re-establishment of the free-edge of the dental lamina, calcification and eruption are presented in Tables 1-2.

The families of cheek-teeth and their generations

A tooth bud was considered to be initiated when the free edge of the dental lamina possessed a terminal swelling bounded both anteriorly and posteriorly by relatively unswollen free edge. In addition each tooth bud could be

Table 1

The development of the cheek-tooth families in the lower jaw.*

Stages	C ₁	dC ₁	P ₁	P ₂	P ₃	dP ₃	M ₁	M ₂	M ₃	M ₄
4 Day						S				
10 Day										
12 Day		S	FE				S			
15 Day			S			FE				
" 22 " Day								S		
21 Day										
28 Day	FE	END	FE			C	FE	C	S	
32 Day	C		C	S				FE		
36 Day								C		
40 Day				FE	C	S			FE	
44 Day									C	S
51 Day										
59 Day										FE?
60+ Day			EG				EG			
83 Day	ED		ED	ED		ED	ED	ED	ED	
105 Day					C					ED

* The stages are approximations based on time from date of birth (with a probable error of less than two days). The animal representing the 22 Day Stage was found to be slightly younger than the 21 Day Stage animal on the basis of relative development. The 60+ Day Stage animal is of unknown age but on the basis of structural development represents a stage between the 59 Day Stage and the 83 Day Stage. The 83 and 105 Day Stage animals were not sectioned. S = initiation; FE = free edge of the dental lamina on the lingual side of the tooth; C = calcification; EG = erupting, i.e. just having pierced the oral epithelium; ED = erupted.

Table 2

The development of the cheek-tooth families in the upper jaw.*

Stages	C ¹	dC ¹	P ¹	P ³	P ⁴	dP ⁴	M ¹	M ²	M ³	M ⁴
4 Day		S								
10 Day	S					S				
12 Day										
15 Day							S			
"22" Day						FE				
21 Day			S			C	FE			
28 Day	FE C							S		
32 Day			FE	S			C			
36 Day			C					FE	S	
40 Day				C	S					
44 Day	END		FE					C		
51 Day										
59 Day								FE		
60+ Day			EG						C	S
83 Day	ED	ED	ED			ED	ED	ED	EG?	
105 Day					C				ED	C

* The stages and abbreviations are the same as those given in Table 1.

identified with its homologue in each consecutive developmental stage either to the stage of eruption, calcification, or in the case of the deciduous canine, resorption. The sectioned stages did not provide the later developmental stages of the P⁴ or M⁴ because of the late initiation of these teeth.

Generally less than five developmental stages after the initiation of a tooth was observed, the terminal free edge of the dental lamina was again visible at the tooth position, lingual to the tooth bud. The tooth bud thus appeared to have risen up the buccal side of the dental lamina relative to the free edge.

With the exception of the deciduous canine, no second generation swellings were observed at established family positions. Therefore, each post-canine tooth family consisted of only one generation of teeth. Although incisor development is not considered here, it should be pointed out that deciduous incisors were present in

association with each incisor position. These generally reached the stage of calcification and were then resorbed.

The identification of cheek-tooth families

The identification of each tooth family that appeared in sequence along the entire lamina from anterior to posterior end was based on the terminology of Thomas (1887). They are in anterior to posterior order: C; P¹; P³; P⁴; dP⁴; M¹; M²; M³; M⁴. Application of these terms to the teeth in question does not mean that I imply any successional relationship between any of the teeth or believe a P² family is lost in the dentition of *Antechinus flavipes*. Thomas's (1887) nomenclature is used simply because it is familiar and widely accepted in connection with Australian metatherians.

The sequence of the establishment of cheek-tooth families

In the earliest stage (4 days post-birth) two family positions are established: the C and the dP⁴. In the upper jaw (the anterior end of the dental lamina of the lower jaw was damaged in the youngest stages) the C was a discrete terminal swelling. The first tooth bud is interpreted to represent a milk canine (dC) as, in the next developmental stage, there is a swollen free edge lingual to the dC which is the homologue of the erupting C. DP⁴ was also a terminal swelling.

Between these two family positions three additional positions were seen to be established in later stages in sequential order as summarized in Tables 1-2: the P¹, P³, and P⁴ positions. More or less synchronously with the appearance of the ante-molar positions, four tooth family positions were seen to be established posterior to the dP⁴; M¹, M², M³ and M⁴.

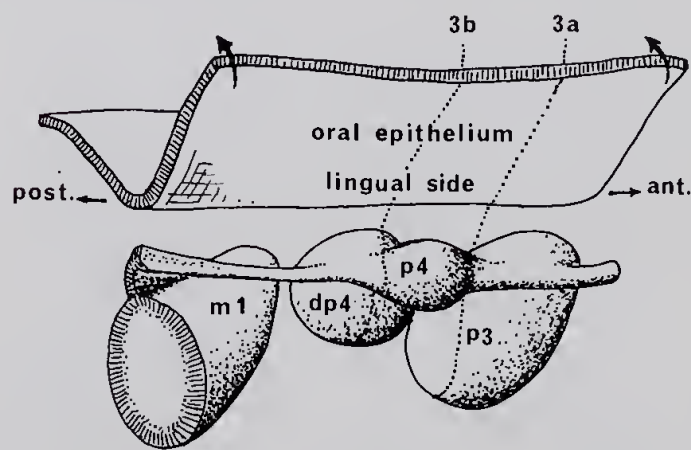


Figure 2.—A schematic portrayal of the region of the lower dental lamina at the 40 Day Stage. The P⁴ occurs as a swelling of the free end of the dental lamina which is by this stage suspended between the lingual walls of the P³ and dP⁴. The mass of the swelling is actually slightly closer to the dP⁴ than it is to the P³. The lingual side of the oral epithelium has been slightly displaced dorsally. Note that the dental lamina has lost contact with the oral epithelium in this relatively late stage (compare with Fig. 6 showing the condition in the 28 Day Stage). Dotted lines 3a and 3b indicate approximate positions of transverse section photographs shown in Fig. 3.

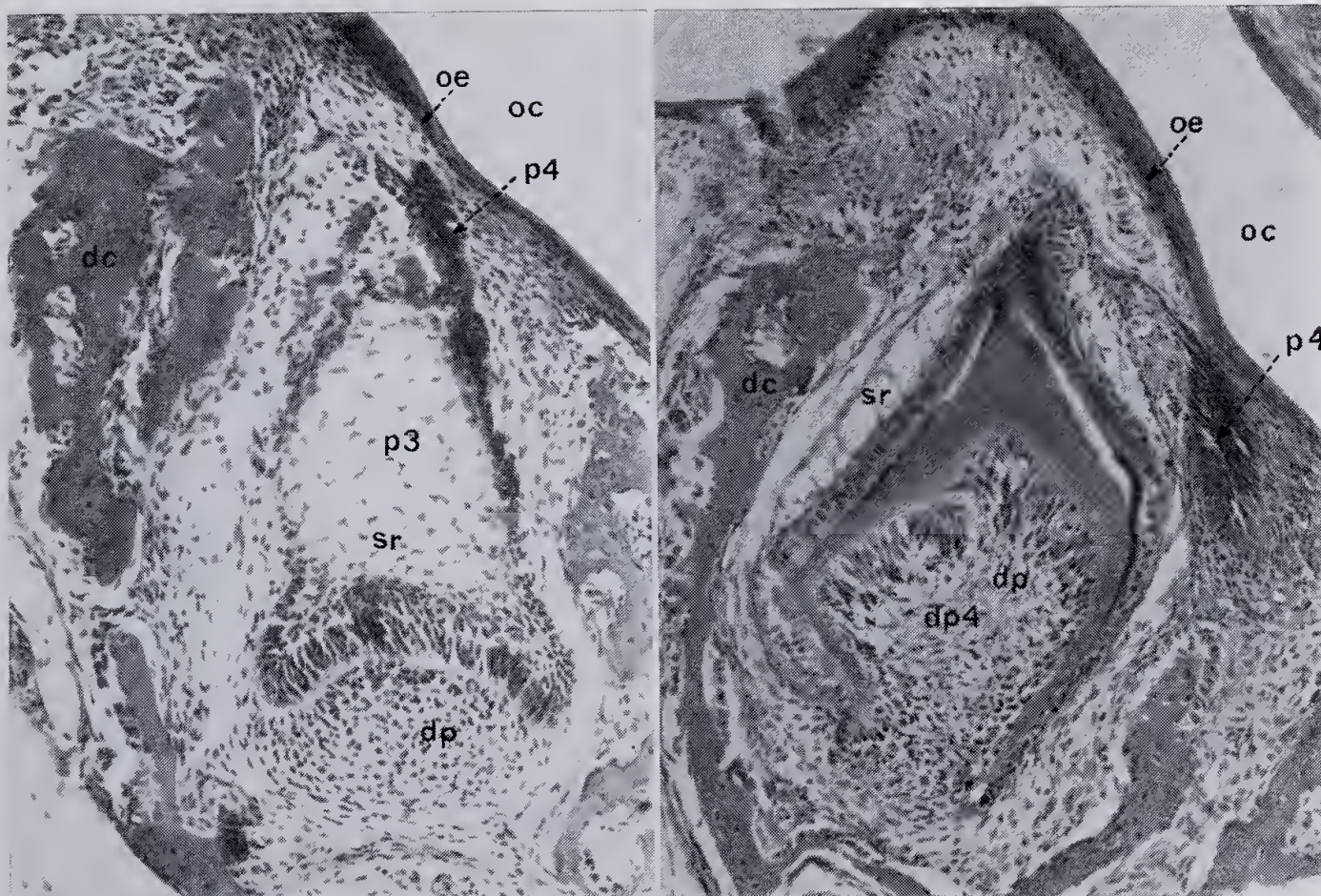


Figure 3.—Photographs of transverse sections of the 40 Day Stage dental lamina. (a) Section through the P₃ near its posterior end where the dental lamina representing the anterior end of the P₄ adheres to the lingual side. (b) Section through the dP₄ where the P₄ swelling is connected to the dP₄ by a thin band of dental lamina. Abbreviations: oe, oral epithelium; oc, oral cavity; dp, dental papilla; sr, stellate reticulum; dc, cartilage of the dentary bone; fe, free edge of the dental lamina.

The form of the dental lamina and its free edge with particular reference to the establishment of cheek-tooth positions

In the earliest stage examined the dental lamina posterior to the C position was of uniform depth, continuous, and in contact with the oral epithelium. In subsequent stages, when tooth initiation had occurred, the dental lamina and/or its free edge associated with the developed tooth appeared to be more distant from the oral epithelium than was the free edge of the inter-tooth dental lamina. In addition, as tooth development occurred there was a tendency to lose contact with the oral epithelium in the region of tooth development. This produced the appearance, particularly in the lower jaw in later stages, of the dental lamina existing as a ribbon stretched or hung between the lingual walls of the developed tooth buds. When the P₄ had initiated, it was flanked anteriorly and posteriorly by two well-developed tooth buds: the dP₄ and the P₃. In the last sectioned developmental stage (60+ Day Stage), the dental lamina connecting P₄ to the surrounding teeth had degenerated, leaving the P₄, which was in that stage still an enlarged swelling of laminar tissue, isolated in the matrix of the lower jaw lingual and anterior to the well-developed dP₄.

In the earliest stages examined, the dental lamina did not extend posterior to the dP₄ position. The dP₄ itself appears to represent a terminal swelling at the posterior end of the dental lamina's free edge. One stage later the dental lamina is seen to extend posterior to the dP₄ and to be swollen slightly to form the M₁.

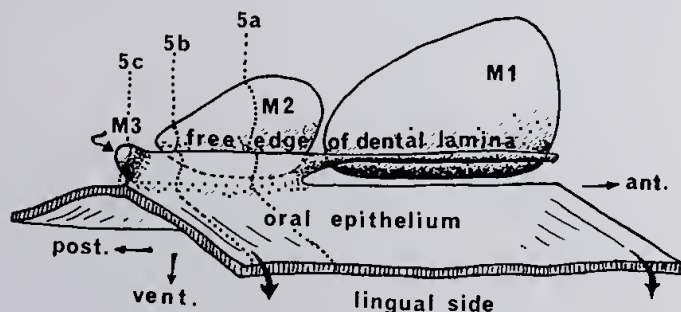


Figure 4.—Schematic portrayal of the dental lamina and associated structures at the 44 Day Stage to demonstrate the upper molar relationships. The lingual side of the oral epithelium has been slightly depressed ventrally to expose the dental lamina. The dental lamina is in contact with the oral epithelium at its posterior edge. The terminal swelling which represents M₃ is continuous with the free edge of the dental lamina lingual to the M₂. In a later stage (the 59 Day Stage) the free edge of the dental lamina is again visible at the M₃ position lingual to the M₃. Dotted lines 5a, 5b, and 5c indicate approximate positions of transverse section photographs shown in Fig. 5.

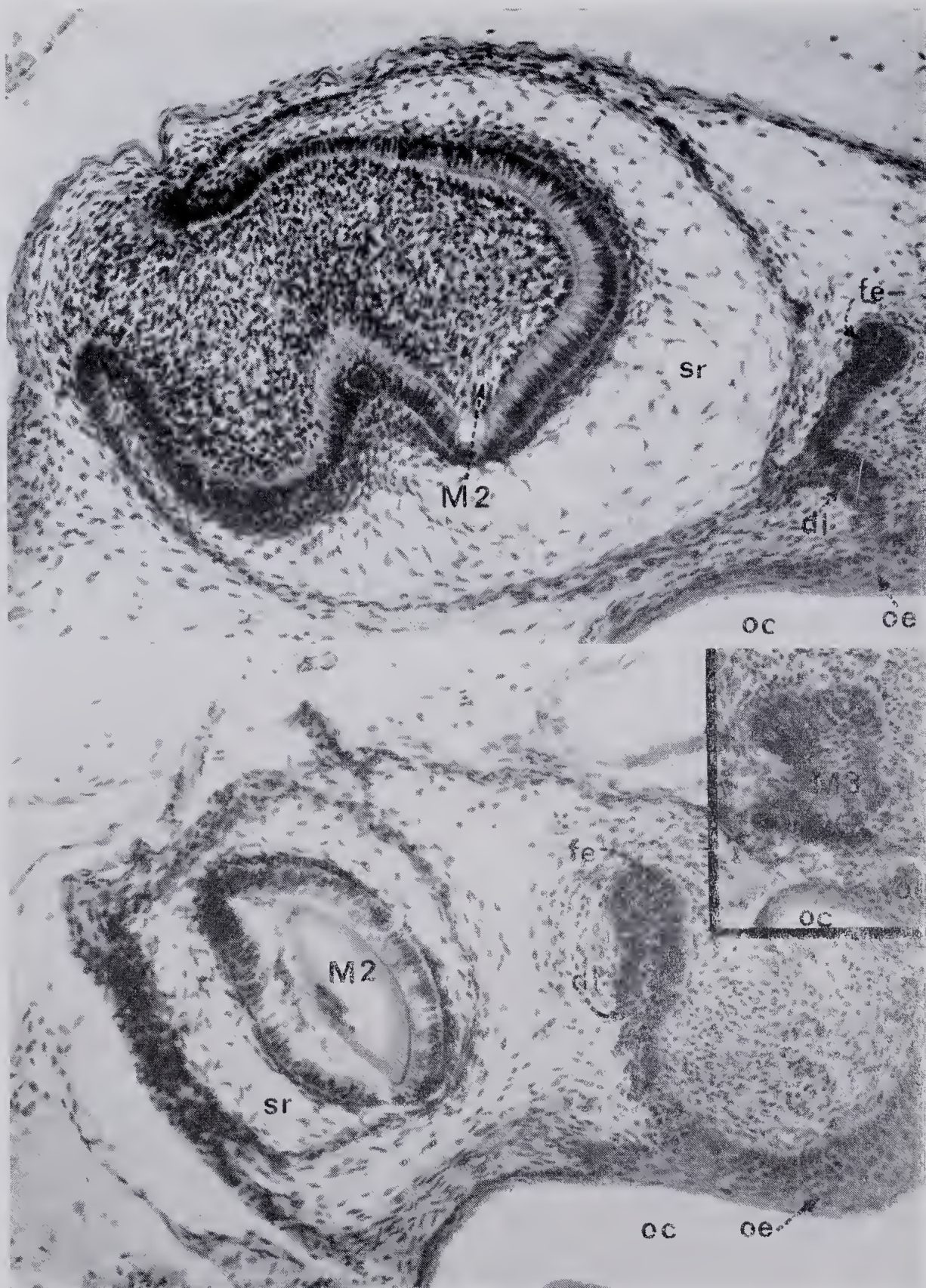


Figure 5.—Photographs of transverse sections of the 44 Day Stage dental lamina. (a) Section through the M² showing its connection with the dental lamina which is in turn connected to the oral epithelium. The free edge of the dental lamina, extending dorsally from the dental lamina on the lingual side of the M³, is sectioned anterior to the point at which it swells to form the M³ swelling. (b) Section through the posterior end of the M² and the free edge of the dental lamina which is attached to the oral epithelium. The free edge is thicker than in (a) above but is still anterior to the position of the M³ swelling. (c) Section through the posterior end of the M³ swelling. Abbreviations as in Fig. 3.

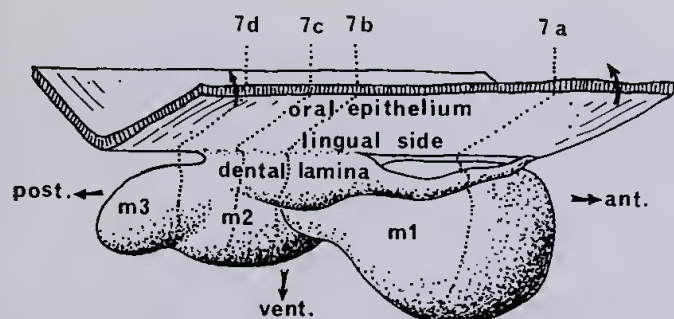


Figure 6.—Schematic portrayal of the lower dental lamina and associated structures at the 28 Day Stage. The lingual side of the oral epithelium has been lifted dorsally to expose the dental lamina. The free edge of the dental lamina has been re-established lingual to the M_1 and in the anterior region of the M_2 . It has not yet been re-established along the posterior edge of M_2 . The posterior region of the dental lamina is not in vertical contact with the oral epithelium and is poorly differentiated from the posterior region of the M_2 . The part that is differentiated lingually and extended terminally represents the initiating M_3 . Dotted lines 7a, 7b, 7c, and 7d indicate approximate positions of transverse section photographs shown in Fig. 7.

At that stage the free edge of the dental lamina is not visible on the lingual side of the dP4. It was, however, visible just prior to the establishment of M_2 .

In the upper jaw the free terminal edge of the dental lamina appears to be more or less vertical in each stage as it is seen to extend farther posteriorly. It maintains continuity with the oral epithelium in the region of posterior growth but further anteriorly, in regions where teeth have been established several stages earlier, the connection with the oral epithelium breaks down. In the upper jaw posterior to the M_1 and in stages after the M_1 is established, the free edge of the dental lamina is seen to be established on the lingual side of the tooth bud prior to, or simultaneously with, the establishment of the next molar position. In the lower jaw the dental lamina is seen to extend posteriorly, in stages post-dating the establishment of the M_1 , such that the ventral free end extends farther posteriorly than the dorsal fixed end in contact with the oral epithelium. This difference in position appears to suggest that the ventral free end extends posteriorly at a more rapid rate than does the dorsal fixed end. As in the case of the upper lamina, in later stages in regions where teeth have been established in several previous stages, the dental lamina is seen to have lost its contact with the oral epithelium. In contrast, however, with the upper lamina, the free edge of the dental lamina of the lower jaw lingual to each tooth is not visible prior to, or simultaneously with, the establishment of the next molar. It does not normally (except in the case of M_3) appear until at least one stage after the initiation of the next posterior molar position.

Discussion

Tooth replacement and the Zahnreihe theory

It is clear that in *Antechinus flavipes* teeth established posterior to the C position are separate tooth families and each has only one

generation. There are therefore no true successional post-canine teeth in the sense of milk and permanent teeth of succeeding generations such as are believed to occur in most eutherians. This supports the observations of Woodward (1893), Engelhardt (1933), Dressel (1931), Litlich (1933), and Berkovitz (1966 and 1967) that the P4 develops from the dental lamina between the P3 and dP4 positions and is not a successor to either. It does not support the contention of Kirkpatrick (1969) that P4 is a successional tooth in the same family as the P3, nor does it support the contention of Wilson & Hill (1897) and other earlier workers that P4 was the successor to dP4.

Berkovitz (1972) describes tooth replacement in the Guinea Pig (*Cavia coby*). He notes that in the upper dentition the so-called replacement premolar develops from dental lamina lying anterior to the so-called deciduous premolar. This is a situation comparable with the condition in *Antechinus* in that the replacing tooth does not develop in a position clearly lingual to the deciduous tooth. However, in the lower dentition of the Guinea Pig, the replacement tooth develops as a lingual downgrowth of dental lamina associated with the posterior half of the enamel organ of the deciduous tooth. Unfortunately, the actual homology of these teeth in Guinea Pigs is uncertain (Berkovitz 1972), and all of the teeth, including the molars may belong to one generation. Ziegler (1972) describes tooth replacement in the eutherian Mole *Scapanus latimanus* and demonstrates that replacement teeth develop from the free edge of the dental lamina that develops from the lingual edge of the deciduous tooth germ. This manner of tooth replacement is unlike that seen in the *Antechinus* dP4 and P4 in the present study, but is comparable with the situation observed here for the deciduous and replacement incisors and canines.

On the basis of the evidence presented in this study, the manner in which the upper M_2 -4 develop in *A. flavipes* is not identical with the manner in which the lower M_2 -4 develop; this difference in ontogenetic behaviour of upper and lower dentitions parallels the condition observed in *Cavia* by Berkovitz (1972, see above). In the posterior region of the upper jaw the dental lamina is firmly in contact with the oral epithelium as new molar positions are initiated. By the time these initiations occur, posterior to M_1 , the free edge of the dental lamina is established on the lingual side of the previous molar. Consequently it is clear that each molar position is a separate family position which subsequently supports or lies buccal to a lingual free edge of dental lamina. This re-establishment of the free edge of the dental lamina appears to be either a passive phenomenon relating to the movement orally of the established tooth germ or else a positive development of the dental lamina as a means of maintaining the developmental potential continuously along the dental lamina. It does not appear to be a necessary prerequisite to the establishment of posterior tooth positions (as Kirkpatrick, 1969,

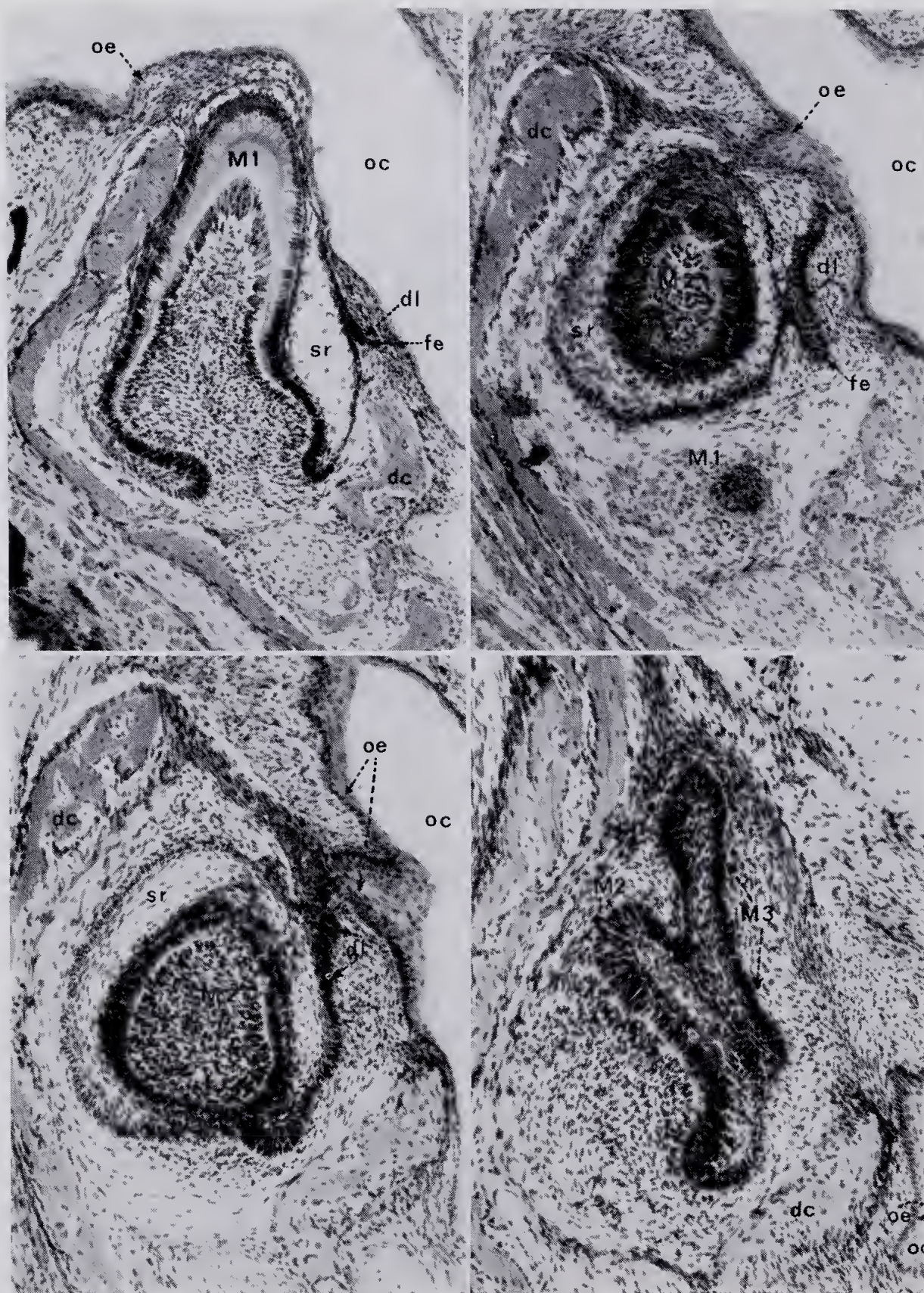


Figure 7.—Photographs of transverse sections of the 28 Day Stage dental lamina. (a) Section through the M_1 showing a small remnant of dental lamina adhering to the lingual side of M_1 and not connected to the oral epithelium at this point. (b) Section through M_1 and M_2 showing contact between M_2 and the dental lamina and the latter with the oral epithelium. (c) Section through M_2 showing the contact between it, the dental lamina and the latter with the oral epithelium. Note the thickened epithelial cells (which is proliferative dental lamina) on the lingual side of the M_2 which marks the anterior extremity of the M_3 swelling. (d) Section through the M_2 and M_3 in the region where they are side by side. The M_3 is developed as an overgrowth of dental lamina passing postero-lingual to the M_2 . At this point neither the M_2 nor the M_3 are in contact with the oral epithelium. Abbreviations as in Fig. 3.

has implied by suggesting that dP4 and M1-4 are successional replacement teeth of one family) as is clearly demonstrated by its retarded re-establishment of the lower dental lamina. This delayed re-establishment of the free edge, as well as the apparent lag in the posterior extension of the junction between the fixed end of the dental lamina and the oral epithelium, constitute the major differences between the development of the lower and upper dental lamina in the molar region. The difference may be caused by the presence of an ascending ramus in the lower jaw. In all later stages, the posterior part of the dental lamina appears to be not only crowded but almost looped. The molars, as they develop, tend to overlap. This could account for the delay in the establishment of a vertical relationship between a lower molar and the oral epithelium which would not or could not occur until such time as the mandible has sufficiently lengthened to permit or facilitate a vertical connection. In the upper jaw, it is clear that bony processes provide no obstacles to development. The developing molars are seen to extend out beneath the orbit where they may be, so to speak, waiting for the maxilla to catch up and provide bony crypts.

Churchill (1935) describes molar formation and its relationship to the dental lamina and oral epithelium in *Homo sapiens*. Except for a slightly more advanced rate of re-establishment of the free edge of the dental lamina, it is a situation remarkably similar to that visualized in this study for the posterior region of the lower dental lamina in *Antechinus flavipes*. He even demonstrates the same difference in the rate of posterior development between the proliferative terminal free edge and the fixed edge of the dental lamina.

The order of initiation of the cheek-teeth in *A. flavipes* clearly suggests that there are in fact two distinct series of temporarily related teeth which are also, in many dasyurids (e.g. species of *Sminthopsis*), distinct morphological series. The molariform series is the dP4-M4. The two series resemble the *Zahnreihen* postulated by Woerdman (1921). Edmond (1960) developed the theory of *Zahnreihen* and suggested that some form of pulse passed along the free edge of the dental lamina initiating, as it passes, tooth buds at predetermined tooth family positions. To explain the unique partial-replacement condition seen in so many eutherians, he visualized first one pulse passing continuously along the free edge, producing all of the milk teeth and permanent molars. Then a second pulse would sweep along the free edge but only for about half the length of the lamina's free edge. The pulse would then stop. This would result in the initiation of a series of second generation teeth developing beneath the anterior teeth, and these would of course represent the permanent replacement teeth. In similar terms, the situation in *Antechinus flavipes* may be that two cheek-tooth centres for the initiation of *Zahnreihen* exist (i.e. C and dP4) and that the two rows of teeth initiated by passing waves

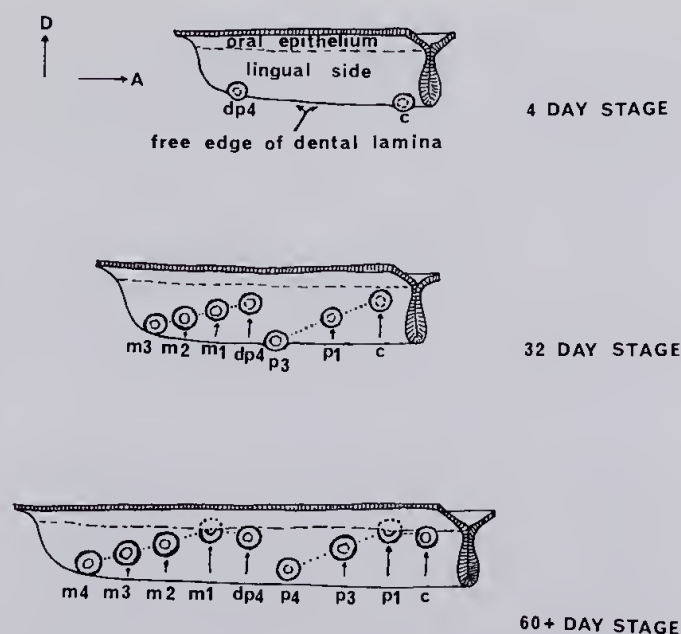


Figure 8.—A schematic portrayal of *Zahnreihen* as evidenced in the developing lower cheek tooth row of *Antechinus flavipes*. Two separate centres for wave initiation are postulated, one at the C family position and one at the dP4 family position. No second generation waves pass the post-canine positions so that no true replacement teeth are initiated in already existing post-canine families. The possibility that a third *Zahnreihe* exists which involves the incisors and the dC1 is discussed in the text. Degenerative changes in the dental lamina are not illustrated in this figure nor is the true nature of the posteriorly extending terminal free edge of the dental lamina (see Fig. 6).

do not overlap because the waves do not overlap at any one family position. The teeth of adjacent families may come to overlap physically after initiation in such a manner that the tooth of one family comes to overlie the tooth of another family giving the appearance of milk-tooth and permanent successor, but this would and does occur only after the sheet of dental lamina has degenerated. In my opinion this is the relationship between the marsupial P4 and dP4.

Incisor development in *Antechinus flavipes* has not been discussed in the present paper because of difficulties encountered in establishing homologues from one specimen to another due to damage in the incisor areas in sectioning which concealed positional relationships, and the added difficulty of the similar morphology of adjacent teeth. It was clear, however, from the material that all incisor families had two generations. The deciduous teeth generally calcified before they were resorbed. It was not clear how these incisor generations are related to the two postulated cheek-tooth *Zahnreihen* because it has not been possible to determine the relative times of development and calcification of the incisors as compared with the cheek-teeth. It is therefore possible that there are more than two *Zahnreihen* present in the toothrow of *Antechinus flavipes*. The deciduous incisors and deciduous canine may represent one *Zahnreihe*, the permanent incisors, canine and premolars the second *Zahnreihe*, and the dP4-M4 the third *Zahnreihe*.

Fosse and Risnes (1972a and b) demonstrate that in the peramelids *Isoodon obesulus*, *I. macrourus*, and *Perameles gunnii*, the I^5 is ontogenetically less developed in the specimens studied than I^4 or C^1 . This suggests the possibility that a separate *Zahnreihe* exists for the incisors, the posterior member of which is the posterior incisor.

Zeigler (1971) has considered the phenomenon of tooth replacement and *Zahnreihen* in mammals. He also concludes that there are two pulses responsible for the production of teeth in mammals but visualizes a greater area of overlap of the two waves than there is evidence for in the present study.

Recently the concept of *Zahnreihen* as visualized by Edmund (1960) has been criticised. Osborn (1970, 1971 and 1972) and DeMar (1971, 1973) have presented alternative hypotheses to explain tooth eruption sequences. Osborn (1970) reviews tooth development in some eutherians and concludes that it does not support Edmund's (1960) contention of two overlapping *Zahnreihen* in mammals. Instead he visualizes between three and six replacement waves. Difficulties which arise from Osborn's interpretation include the need to allocate homologous teeth (e.g. the permanent canines) of different genera to different *Zahnreihen*. Osborn believes this may not be a problem providing the *Zahnreihen* are not visualized as immutable. Osborn (1971) presents evidence for believing that, in *Lacerta*, *Zahnreihen* as visualized by Edmund (1960) are not involved in tooth production. DeMar (1971, 1973), working from data including Osborn's (1970) summary, proposes new geometric ways of interpreting tooth eruption. Neither Osborn nor DeMar, however, make reference to marsupial tooth eruption sequences. This is unfortunate, as it is perhaps only in the marsupials that mammalian tooth eruption sequences of the sort proposed by Edmund appear to take place. The data presented in the present study indicate that, contrary to Osborn's (1970) opinion, the teeth do in fact develop and erupt in sequence from anterior to posterior along the dental lamina in the order which is required by passing waves of the *Zahnreihe* theory.

Osborn (1972) has since developed his earlier (1971) idea and suggests that tooth initiation may be a function of released inhibition. Although the observations reported here are described as *Zahnreihen*, they could equally well be interpreted as the result of released inhibition. More work with other polyprotodont marsupials will be required before the process of tooth initiation in marsupials is understood. In particular, close attention should be given to longitudinal growth of the dental lamina between established tooth positions.

The possibility must remain that tooth eruption sequences in eutherians and marsupials are fundamentally different because there would seem to be no diphyodonty in the cheek-teeth of marsupials and the two *Zahnreihen* have no overlap. It has long been held that the two groups have markedly different patterns of

diphyodonty (in that only the last premolar was replaced) as well as differences in cheek-tooth numbers.

Premolar number and terminology

Although it does seem probably that eutherians and metatherians originally had the same number of premolar positions, there does not seem to be enough information available to determine which premolar position has been suppressed in the metatherians. Archer (in preparation) demonstrates that supernumary premolars are known to occur in dasyurids anterior to the P1, between the P1 and P3, and even posterior to the P4. Accordingly, arguments for particular premolar family loss based solely on teratology are unsound.

The concept of missing P2

Ride (1964) and Mahoney & Ride (1974) have summarized some aspects of premolar homology in marsupials. The premolar terminology used by Ride is that used by Thomas (1887). Thomas argues that the occasional appearance of an extra premolar between P1 and P3 is an atavistic reappearance of a suppressed tooth homologous with the eutherian P2. Accordingly he proposes that the normal marsupial premolars be called P1, P3, and P4. However, no one has demonstrated clear embryological evidence for a suppressed tooth family in the P2 position. Woodward (1896, p. 184) claims to have found it as "... an enormous gap between pm1 and pm2 both above and below, this is bridged over by dental lamina, which shows a slight indication of being swollen, this probably represents Thomas' missing pm2, the adult premolars being the 1st, 3rd and 4th." He notes this in *Antechinus* and a similar development (p. 286) in *Dasyurus*. There was however no evidence for a P2 family position in the *Antechinus flavipes* examined in the present study.

The concept of a missing P1

Ziegler (1971) has recently re-examined concepts of premolar loss in mammals and has concluded that all the marsupials and most eutherians have lost a premolar from the anterior end of the premolar row. In this he has reached the same conclusion as Owen (1840-45), but I know of no embryological evidence for this loss in marsupials. Ziegler has pointed out that in mammals premolar loss generally proceeds by loss first of the replacement tooth followed by loss of the deciduous tooth in a tooth family. This loss proceeds from anterior to posterior along the premolar row. I can find no palaeontological or ontological evidence for these trends in marsupials.

The concept that the premolariform series is complete but that P4 may occasionally be lost

The evidence that is available suggests that C-P4 is a complete unit representing a *Zahnreihe* but that in dasyurids there is a general trend towards reduction of the posterior premolar family, with loss of this tooth in several

dasyurid genera (*Dasyurus*, *Dasycercus*, *Dasyuroides*, some *Antechinus*, some *Planigale*, and some *Myoictis*).

This study shows that there are no true premolars in *Antechinus flavipes* if premolars are defined in the terms of Owen (1840-45) as those post-canine teeth which possess milk predecessors. This definition is the basis of the modern dental terminology applied to the cheek-teeth of mammals. However, it is clear that there are two different morphological kinds of cheek-teeth in *Antechinus flavipes* and that the teeth of each of the two kinds (i.e. premolariform and molariform) have a unity in origin best expressed by the concept of *Zahnreihen*. If studies of other metatherians demonstrate a similar situation, it may be desirable to redefine the kinds of cheek-teeth and to develop a nomenclature that reflects the *Zahnreihen*.

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9.—Amygdaloidal rock from Watheroo in the Permian Nangetty Formation, Western Australia

by J. E. Glover¹

Manuscript received 18 September 1973; accepted 16 October 1973

Abstract

Amygdaloidal igneous rock has been recovered from the glacial Nangetty Formation at Tillite Creek in the Irwin River valley, Western Australia. The amygdaloids contain quartz, calcite, chlorite and epidote and are the same in other respects as amygdaloids in dolerite near Watheroo, 150 km south of Tillite Creek. The identity of these distinctive rocks confirms the essentially northward direction of Permian glacial transport suggested for the area, and may help to define the movement rather precisely.

Introduction

The Permian (Sakmarian) Nangetty Formation crops out in the valleys of the Irwin, Leckier, Greenough and Murchison Rivers in the northern part of the Perth Basin (Fig. 1). Its glacial origin was recognized by Campbell (1910) and confirmed by Woolnough and Somerville (1924), and details of the formation at Tillite Creek were given by Clarke, Prendergast, Teichert and Fairbridge (1951). The last-named authors described many rocks from the heterogeneous assemblage, and realized that some boulders of quartzite, breccia and chert have counterparts to the south in what has since been named Coomberdale Chert (McWhae *et al.*, 1958, p. 12). Most of the other material at Tillite Creek mentioned by Clarke *et al.*, i.e. "reddish or blackish hard fine-grained mudstone", gneiss, pegmatite, quartz-epidote rock, mica schist, quartz schist, porphyry, four varieties of granite and three varieties of epidiorite are believed to come from Archaean terrain east of the roughly north-south band of Moora Group rocks. Details of their provenance, however, have not been established.

Since the work of Clarke *et al.*, a glacial deposit at Bindoo Spring, 60 km northwest of Tillite Creek, has been examined by many geologists. This deposit contains fragments first identified by Playford and Willmott as Mt Scratch Siltstone, Enokurra Sandstone, Arrow-smith Sandstone, Beaconsfield Conglomerate and Arrino Siltstone, and their derivation from the Yandanooka area to the south-southeast is certain. There are also representatives of the Moora Group, and shield rocks east of the Darling Fault.

The above data provide the main evidence for the generally accepted view that the direction of Permian glacial transport in southwestern Western Australia had general westerly and northerly components (see for example Crowell & Frakes 1971, Fig. 10a). Apart from the work

of Clarke *et al.*, few details of the evidence have been published, though most of it is in an unpublished report by Playford & Willmott.

This paper records the discovery of two new rock types at Tillite Creek, both of which have counterparts near Watheroo, 150 km to the south. One of the rocks, a red-brown siltstone with coarse dolomite grains resembles part of the Dalaroo Siltstone 2 km northwest of Watheroo. The other, with which this paper is concerned, is an amygdaloidal igneous rock of distinctive mineralogy and texture. Virtually identical rock has been recorded from bodies of rock that intrude and slightly metamorphose Dalaroo Siltstone within a strip of country 4 × 8 km immediately northwest of Watheroo by Teoh 1967 (see Fig. 1). The Tillite Creek rock (68275)* and a specimen of amygdaloidal rock from Watheroo (60145) are described below.

Petrography of the amygdaloidal rocks

The igneous rock from Tillite Creek is grey-green and fine- to medium-grained and contains irregularly shaped to roughly ovoid, black,

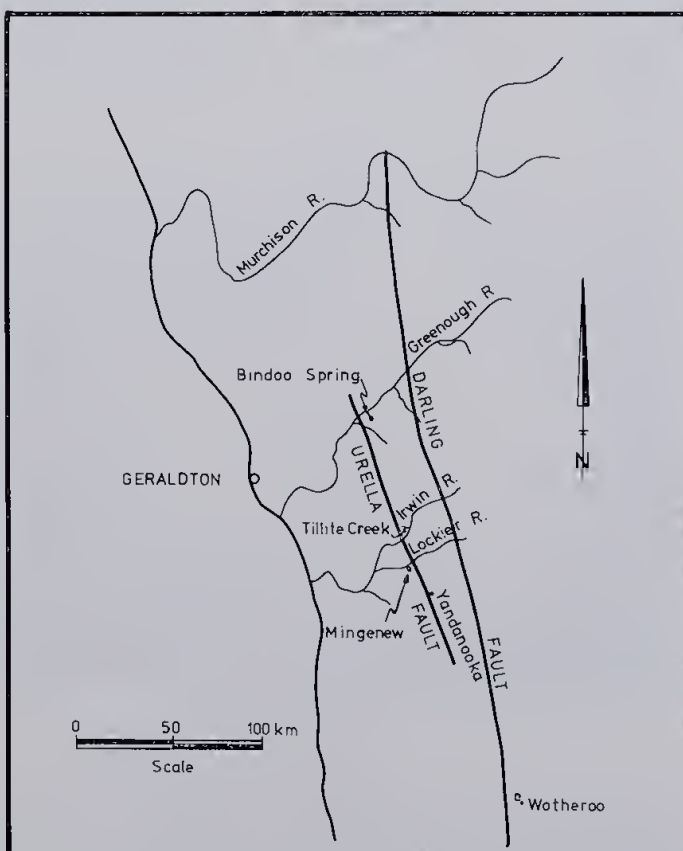


Figure 1.—Locality map showing Watheroo and Tillite Creek. The small rectangle north-west of Watheroo is the area within which amygdaloidal dolerite has been mapped by Teoh (1969).

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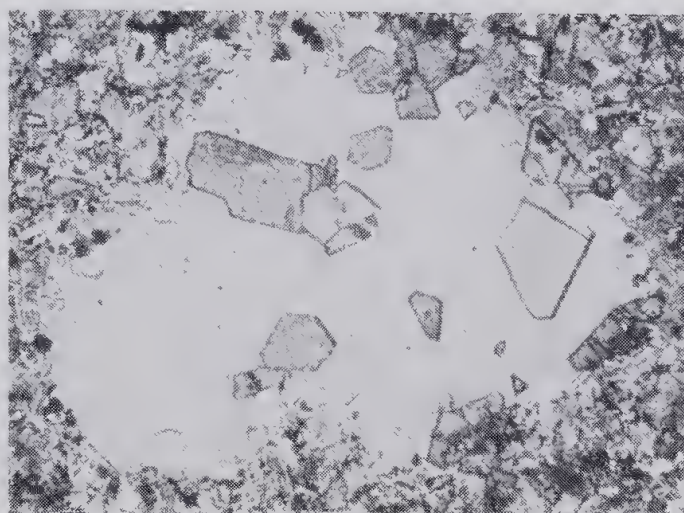
* All specimen numbers refer to the collection of the Geology Department, University of Western Australia.

and grey and black bodies up to a centimetre long that resemble amygdales. Under the microscope about 60% of the rock between the amygdales is made up of highly altered plagioclase laths with no apparent preferred orientation, and the rest is largely chlorite. There appears to be a palimpsest ophitic texture, but pyroxene is absent. There are numerous irregularly shaped masses of calcite in the rock; some plagioclase grains are completely converted to calcite, but most are only partly carbonated, and are charged with chlorite flakes. The unaltered plagioclase ranges from oligoclase to andesine. Epidote and sphene are scattered throughout the rock, and a few grains of hematite, pyrite and a black opaque iron mineral are present.

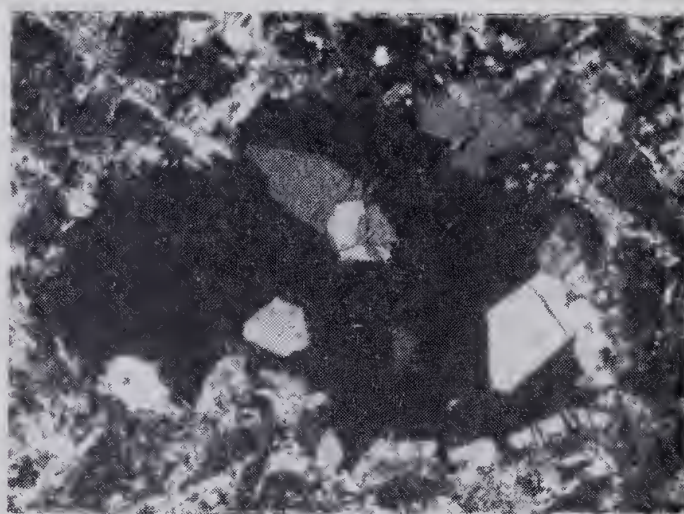
About 5% of the rock consists of the irregularly shaped to roughly ovoid bodies visible

in hand specimen. In their most characteristic form they resemble amygdales and have a narrow discontinuous rim of calcite and quartz with a core of clear green, practically isotropic chlorite containing euhedra of epidote (see Fig. 2). Where the chlorite shows faint anisotropism, the anomalous interference tints suggest a micro-drusy structure of which there is little indication without the analyser. There is a tendency for grains of sphene in the rock to be concentrated near the margins of these apparent amygdales. In some places the quartz of the rim is lath-like, and seems to have replaced plagioclase.

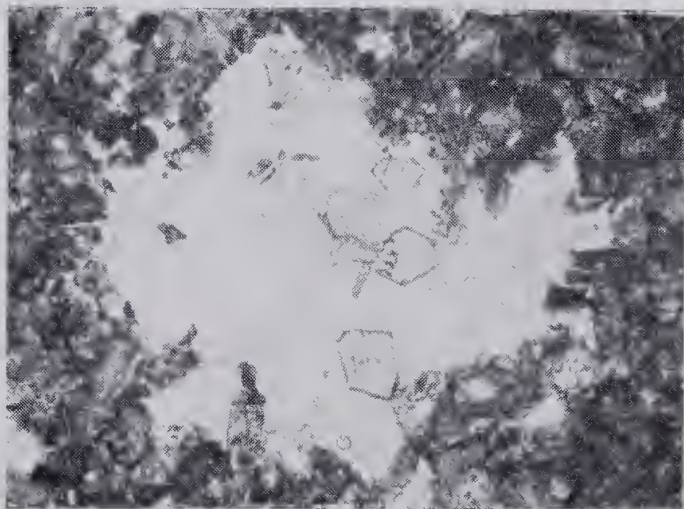
Eight of the epidote crystals in the bodies described above were measured with the universal stage. Forms identified are {001}, {100}, {110}, {101} and {111}. Six-sided crystals showing the front and basal pinacoids and a dome



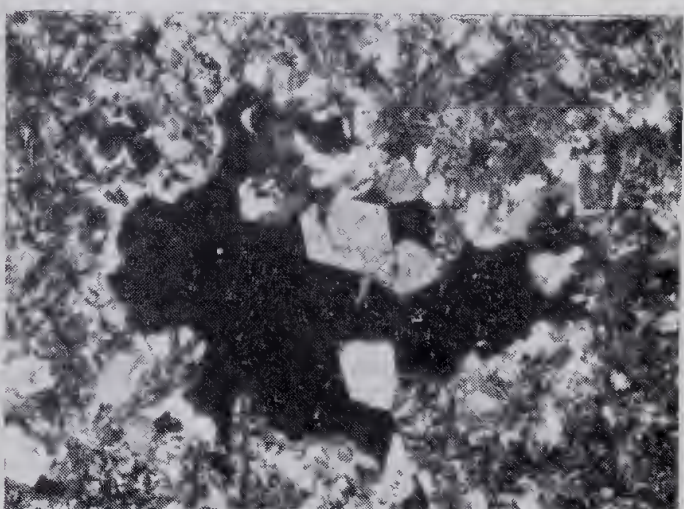
A



B



C



D

Figure 2A.—Specimen 68275 (altered dolerite) from Tillite Creek. Note the amygdale filled mainly with chlorite (light grey), euhedra of epidote (grey with dark borders), and the discontinuous rim of quartz (white). Small dark grains outside the amygdale are sphene. Plane-polarized light, x 25. Univ. West. Aust. Geol. Dept. negative No. P2612. B.—Specimen 68275, same amygdale illustrated in Figure 2A. The chlorite is black, and some epidote shows twinning. Crossed polarizers, x 25. Univ. West. Aust. Geol. Dept. negative No. P2613. C.—Specimen 60145 (altered dolerite) from Watheroo. Note the amygdale filled mainly with chlorite (light grey), the euhedra of epidote (grey with dark borders), and the discontinuous rim of quartz (white). The small dark grain in the amygdale (left centre) is sphene; most of the sphene is just outside the amygdale. The resemblance to specimen 68275 from Tillite Creek is clear. Plane-polarized light, x 36. Univ. West. Aust. Geol. Dept. negative No. P2610. D.—Specimen 60145, same amygdale illustrated in Figure 2C. Crossed polarizers, x 36. Univ. West. Aust. Geol. Dept. negative No. P2611.

are common in thin section, and some show twinning on 100. The pleochroic scheme is $X = \text{colourless}$, $Y = \text{pale yellow}$, $Z = \text{olive-green}$ with absorption $X < Y < Z$. Dispersion is pronounced with $r > v$ and $r < v$ in different crystals, suggesting crossed dispersion. $X_{\lambda c}$ (7 grains) measures 2° , 4° , 5° , 5° , $5\frac{1}{2}^\circ$, 6° , 7° , and $(-)$ 2V (4 grains) measures 68.5° , 69° , 70° , 75° , with measurements reproducible to within 2° . These properties are the same as those for epidote in the pistacite range (Winchell & Winchell 1956, Fig. 343).

There are other bodies in the rock in which the minerals are arranged differently. In a few the calcite rim is thick and continuous, and chlorite is restricted to a small core. Some of the bodies have a discontinuous rim of quartz, an irregularly shaped inner layer of slightly fibrous chlorite containing epidote euhedra, and a core of granular calcite and very fine grained quartz. Other, commonly complex bodies, have cores either of calcite or microcrystalline quartz. Some very irregularly shaped masses, generally made up essentially of chlorite, epidote and calcite, have only vaguely defined boundaries with the surrounding chlorite-rich and calcite-rich groundmass, and have the appearance of having replaced the rock rather than having filled cavities in it. Nevertheless, for simplicity all these bodies are from now on called amygdaloids, and they have one consistent feature: the epidote either penetrates the chlorite or is enclosed by it.

The amygdaloidal rocks at Watheroo resemble the Tillite Creek specimen described above. Specimen 60145 was collected from a dyke-like body that roughly parallels and locally crosses the Geraldton Highway between about 5 kilometres and 10 kilometres north of Watheroo. Outcrop of rock similar to that of specimen 60145 is found 0.15 kilometres north of the Longreach turnoff, 9 kilometres by road north of Watheroo.

Specimen 60145 is grey-green, fine-to medium-grained, and contains irregularly shaped to roughly avoid, black, and light grey and black bodies up to a centimetre in diameter. In thin section there seems to be a relict ophitic texture, but in places where most of the original minerals have been changed, there is little evidence of such texture. Laths of plagioclase have commonly been replaced by chlorite, epidote and calcite, and locally by quartz. Interstitial material consists partly of pale brown and pale green fibrous amphibole, very rarely with a core of augite. There are also irregularly shaped patches of chlorite and calcite, and epidote in the form of clear crystals and cloudy fine-grained aggregates is common. Other constituents include small grains of sphene, an opaque mineral (probably leucoxene) and fine aggregates of interstitial quartz. The rock is probably an amygdaloidal quartz dolerite that has been extensively auto-metamorphosed.

Some amygdaloids resemble those in the Tillite Creek boulder very closely (Fig. 2). In general, they have the same mineralogy and show the same range in mineral arrangement and their contained epidote euhedra exhibit the same morphology and pleochroism. There is a similar

tendency for small grains of sphene to be concentrated in the rock near the amygdaloids. Measurements with the universal stage on epidote in specimen 60145 are as follows: $X_{\lambda c} = 3\frac{1}{2}^\circ$, 5° (2 grains) $(-)$ 2V = 70° , 71° (2 grains). Dispersion is pronounced with $r > v$ and $r < v$ in different crystals, suggesting crossed dispersion. The epidote is thus indistinguishable optically from epidote described in the Tillite Creek rock.

Other similar Watheroo rocks contain amygdaloids with a higher proportion of epidote, and grade into rocks in which the epidote resembles glomeroporphyritic aggregates.

Discussion

Epidotized amygdaloidal rocks have been recorded from the Proterozoic Fish Hole Dolerite in the Kimberley Region by Dow & Gemuts (1969, pp. 28, 30-31), but apart from the Watheroo rocks, intrusive amygdaloidal bodies have not been reported elsewhere in Western Australia. The striking similarity of the material from Tillite Creek and Watheroo makes their common origin very likely.

The amygdaloidal dolerite at Watheroo was mapped as dykes cutting the Dalaroo Siltstone both by Teoh (1967), who discussed its petrology, and by Low (1969), who did not distinguish it from the other, non-amygdaloidal dolerite in the area. The strike of the amygdaloidal dolerite parallels that of the Moora Group fairly closely, and it may be at least locally concordant. Detailed mapping is necessary to check its structural relationships to the Dalaroo Siltstone and to determine its extent. It has not been recognized far north of Teoh's area, and is known to be absent from the Moora area. If it proves to be restricted to the vicinity of Watheroo, it will demonstrate rather precisely the direction of travel of Permian ice eroding the Watheroo area, and will indicate the distances of transportation involved.

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10.—Australites of mass greater than 100 grams from Western Australia

by W. H. Cleverly¹

Manuscript received 20 November 1973; accepted 18 June 1974

Abstract

Seventeen australites from Western Australia in the mass range 100-437 g and including the most massive australite known have been examined. Most of the other fifteen previously recorded Western Australian specimens in that range have been re-examined. All are round, oval or dumbbell shaped cores. Where possible, the forms and dimensions of the primary bodies have been assessed and thence the percentage losses involved in forming the remnant cores. Average volume loss was only 46%. The distribution of the sites of find has been considered and the south western portion of the state is confirmed as the principal area of infall of australites of mass exceeding 100 grams. The distribution suggests the possibility of mass grading related to the northern boundary of the australite strewnfield.

Introduction

Australites (Australian tektites) of mass exceeding 100 g are rare, comprising only a few hundredths of one percent of known specimens. The purposes of this paper are to describe 17 Western Australian specimens in the mass range 100 to 437 g and to supply additional details for any other available specimens for which published descriptions are incomplete.

Because all australites under consideration are remnant shapes from which a stress shell has spalled, they have certain morphological features in common. A general procedure was therefore possible when examining the specimens.

General principles and procedure

Larger specimens were weighed on a Mettler, K-type, top-loading balance which had also arrangements for bottom suspension of the specimen in de-ionized water for determination of specific gravity; for lighter specimens and chips, a more sensitive chemical balance was used (Table 2, cols. 6 & 8).

The conventional statement of dimensions in the sequence length, breadth and thickness (Table 2, col. 7) has a simple relationship to australite orientation during flight downwards through the atmosphere. Because nearly all australite primary bodies were either spheres or rotational shapes with considerable symmetry, they almost invariably adopted a stable flight orientation, generally presenting a broad face forward. Thus the length and breadth (or a diameter) were in a plane normal to the line of flight and the thickness was parallel to the line of flight. The thickness was especially reduced during flight and the length and breadth

were also affected, but the same relationship of the dimensions to the flight orientation generally applies to the remnant core as for the primary body. The plan view in flight position is thus a view of the posterior surface of flight looking in the direction of flight and this view shows length and breadth or diameter. The plan view dimensions of australite cores are often but not necessarily defined at the level of the rim (see below).

The shape type of the core (Table 2, col. 2) is the shape seen in plan view. Ideally, a round core is perfectly circular in plan view. Weathering may lead to differences of 2-3 mm in the dimensions of a core of (say) 50 mm diameter, but classification as a round core may be preferred. Similarity of the various profiles through the posterior pole of the core is also a criterion which aids the distinction between round and broad oval cores; the distinction is none the less subjective. The arbitrary width/length ratios of Fenner (1940 p.312) were applied strictly in defining broad oval, narrow oval and boat shapes, resulting in a nomenclature change for one previously described specimen (No. 28, Table 2). The dumbbell shape is self-explanatory.

Most well-preserved large cores have a rim separating the posterior surface of flight from the surface exposed by loss of the stress shell. The posterior surface is a modified remnant of the surface of the primary or parental body which suffered shape modification during passage downward through the earth's atmosphere. The form of the posterior surface is thus a guide to the form and dimensions of the primary body. The stress shell was a shell of glass a few millimetres thick immediately beneath the anterior surface of flight where fusion and ablation stripping were active during the earlier hypersonic phase of atmospheric transit. The shell had been first heated and then cooled. Opinions differ as to the timing of the loss of the stress shell—whether in a late stage of flight, on impact, or as the result of terrestrial processes such as diurnal temperature changes. Small cores retaining partially detached portions of the stress shell are not uncommon, but specimens of this kind (known as "indicators") are unknown amongst cores of mass exceeding 100 g, evidently because the greater total amount of expansion and contraction resulted in a more efficient spalling of the shell. The surface exposed by loss of the stress shell may be relatively irregular when compared with the posterior surface.

Thus, on well preserved cores, the relatively smoothly curved posterior surface terminates at a rim anterior to which the dimensions decrease

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to those of the surface exposed by loss of the stress shell. Correct interpretation of the "facing" of the rim is critical to identification of the posterior surface of flight and hence to deductions concerning the form and dimensions of the primary body. In a few specimens, terrestrial weathering has removed or considerably modified parts of the rim, but in only one of the specimens under consideration was the flight orientation in doubt.

Anterior to the rim on the surface exposed by loss of the stress shell (the present anterior surface as distinct from that of flight) there may be a distinct shoulder inherited from the ablation form (see for example Fig. 3-17). In such examples an equatorial zone is defined between the natural limits of rim and shoulder. In others, the shoulder is indistinct or absent and the anterior limit of the equatorial zone is then ill-defined, or the zone may exist only in the sense that it usually has a distinctive minor sculpture (Fig. 2-9).

The form of the posterior surface was estimated by fitting curves to profiles traced on enlarged silhouettes projected with a lantern, the specimen being oriented as in flight. The degree of enlargement used (about $\times 4$) was calculated for each by comparison of the dimensions of the silhouette with those of the specimen. Profiles were traced on cm-mm graph paper with the rim of the specimen aligned with one set of lines of the paper.

When a core is circular in plan view, or nearly so, and the constructed arcs of circles fit closely the various profiles through the posterior pole of the specimen as seen in side elevation and have much the same radius, it is assumed that the primary body was a sphere.

When a core is elongate and the posterior surface has distinctly different transverse and longitudinal profiles in side elevation, a simple possibility is that the parent body was a prolate spheroid which oriented with the long axis normal to the flight path. For such spheroids the radius of the arc fitted to the transverse profile through the posterior pole is identical with the semi-minor axis of the elliptical longitudinal profile. The mathematical origin of the ellipse was plotted, and by using the coordinates of a point on the best preserved part of the longitudinal profile in the general equation of the ellipse, the semi-major axis was calculated. The positions of the foci were then calculated and an ellipse drawn to test the correctness of fit. Except when badly eroded (e.g. No. 28) these specimens presented little difficulty.

When a core is round and all profiles through the posterior pole are closely the same ellipse, the core was probably derived from an oblate spheroid which oriented with the short axis parallel to the flight path. Unlike the previous example, neither semi-axis of the ellipse is directly measurable. The method used was to judge the approximate position of the major axis, calculate the ellipse as before, and draw a trial ellipse on tracing paper superimposed on the diagram. The position of the major axis was then adjusted 8 mm (i.e. c. 2 mm on

true scale) and the calculation repeated. In general, three or four trials with reduced degrees of adjustment sufficed to produce a well fitting ellipse, the dimensions of which were known to 1 or 2 mm on true scale. Mathematical methods could probably be devised e.g. by fitting a regression line to points selected from the best preserved parts of the profile, but such methods tend to give a rather spurious aura of precision to these estimates based upon pitted and otherwise imperfect surfaces. Neither was a lens measure used in a quantitative way, but it was found to be a valuable aid for the detection of non-spherical surfaces. A narrow, double thickness (0.05 mm) of transparent adhesive tape with interleaved strip of cm-mm graph paper was attached along the profile to be examined to smooth out minor irregularities before applying the lens measure. Lens measure readings taken along six profiles outward from the posterior pole of specimen No. 5 (Table 1) illustrate the increasing degree of curvature towards the rim of a surface which, to the eye, appears to be part of a sphere (Chapman 1964 Fig. 6A).

Table 1

Lens measure readings for posterior surface of australite core from Lake Yealering

Distance between mid point of lens measure and posterior pole of core	Range of lens measure readings for six profiles	Mean lens measure reading for six profiles
cm	units	units
1	10.5-13	12.2
1.5	11.5-15	12.7
2	12-16	14.0
2.5	14-18	16.0
3	15.5-18.5	17.5

Arcs of circles will fit considerable lengths of ellipses to within the thickness of construction lines (see for example Baker 1956 Figs. 21, 31, 32). As ellipticity increases, the possibility of detecting departure from spherical shape improves and it is also better in those specimens where losses from the primary body have been relatively small. Blown sand or other terrestrial agents can cause complications e.g. by flattening the polar area of the spherical surface of a core to produce a form approximating an oblate spheroid. If an oblate spheroid with the short axis parallel to the line of flight is mistaken for a sphere, the volume of the primary body will be over estimated and likewise the percentage losses (see below). A round core calculated as a sphere and having unusually high loss figures may therefore be suspected as having been derived from an oblate spheroid.

The writer finds it difficult to believe that a prolate spheroid would be stable with the long axis parallel to the flight path, but if such a spheroid were incorrectly calculated as a sphere, the volume of the parent body would be underestimated and this could become evident as unusually low percentage losses.

Table 2

Masses and dimensions of australite cores from Western Australia and of their primary bodies

No.	Shape Type	Site of find	Long E.	Lat. S.	Mass g	Dimensions mm	S.G.	Primary body		% Losses		Source of Data
								Dimensions cm	Mass g	Mass	Depth	
1	Broad oval	c.3 km W. of Notting	118°14'	32°27'	437.53	83.7 x 72.1 x 54.5	2.425	10.2 x 8.4 x 8.4	914	49	35	Baker (1962)
2	Broad oval	c.16 km S.E. of Warrakakin	118°41'	31°08'	(265) 238.00	(70) 65 x 62.5 x 42	2.409	8 x 7 x 7	494	47	40	
3	Round	Newdegate	119°02'	33°06'	243.05	62 x 58.6 x 55.1	2.424	6.4 diam.	333	37	14	Cleverly (1971)
4	Broad oval	c.14 km W. of Kondinin	118°07'	32°30'	233.92	64.8 x 58.9 x 50	2.435	7.4 x 6.4 x 6.4	386	38	22	
5	Round	Lake Yealering	117°38'	32°36'	218.05	67.9 x 66.9 x 41.4	2.433	7 x 7 x 5.1	318	46	19	
6	Broad oval	On W. end Lake Ballard	120°36'	29°21'	200.29	60 x 57 x 44	2.435	8.4 x 7.8 x 7.8	652	69	44	
7	Broad oval	Narrogin or Narenbeen	118°05'	32°27'	(200) 194.78	67 x 56.4 x (40.6) 39.3	2.437	8.6 x 7.1 x 7.1	557	64	43	
8	Round	c.18 km W. of Notting	118°28'	33°48'	194.40	57 x 55 x 49.5	2.423	6.4 diam.	333	42	23	Baker (1966)
9	Round	c.19 km N. of Ongerup	118°28'	33°48'	184.07	55.6 x 55.5 x 48.6	2.423	5.7 diam.	226	19	15	
10	Dumbbell	Cuballing	117°11'	32°49'	175.996	100 x 42 x 33.7	2.435	8 diam.	653	74	53	Baker (1963)
11	Round	Graball	118°34'	32°02'	168.28	60.9 x 58.7 x 37.5	2.434	6.6 x 6.6 x 6.4	358	53	31	
12	Round	5 km S.E. of Corrigin	117°54'	32°22'	167.98	56.9 x 55.8 x 43.8	2.427	6.4 diam.	331	49	30	Simpson (1939)
13	Round	c.25 km S.W. of Chillingup	118°25'	34°29'	167.28	56.8 x 56.3 x 44.5	2.410	6.4 diam.	331	49	30	
14	Round	Between Narrogin & Merredin	118°25'	34°29'	(c.154) 152	57 x 55 x 39	2.42	6.4 diam.	331	49	30	Baker (1967)
15	Dumbbell	c.16 km N.W. of Ongerup	118°21'	33°52'	151.286	98.4 x 35.6 x 29.6	2.433	5.4 x 5.1 x 5.1	180	17	7	
16	Broad Oval	Kalgarrin	118°42'	32°30'	(149) 126.75	52.2 x 49.7 x 47.4	< 2.439	6.7 diam.	383	62	39	Baker (1967)
17	Round	Near Corrigin	117°52'	32°20'	147.00	54.3 x 52.9 x 41	2.434	6.7 diam.	383	62	39	
18	Round	Lake Grace	118°28'	33°06'	(143) 134.50	53 x 52.5 x 43.5	2.409	8.3 x 4.8 x 4.8	242	48	37	
19	Narrow oval	26 km E. of Kulin	118°26'	32°40'	(133) 131.49	79.6 x 43 x 30.2	2.420	6.1 x 6.1 x 3.6	171	30	13	
20	Round	Lake Buchanan	c.123°00'	c.25°30'	(120) 116.06	55.8 x 55.1 x 31.3	2.439	6.1 x 6.1 x 3.6	171	30	13	
21	Broad oval	Babakin	118°01'	32°07'	(117) 113.07	51.4 x 46.3 x 37.2	2.432	7 x 5 x 5	222	47	36	Baker (1961)
22	Broad oval	c.8 km E. N.E. of Wickepin East	117°44'	32°45'	116.94	61.3 x 51.3 x 32.2	2.429	5.1 x 4.7 x 4.7	141	19	8	
23	Broad oval	Narenbeen	118°23'	32°04'	114.55	46.9 x 45 x 43.6	2.430	5.1 x 4.7 x 4.7	223	50	31	
24	Round	Moulvintine	117°56'	33°14'	111.15	48.7 x 46.7 x 38.7	2.421	5.6 diam.	156	36	20	
25	Round	Norseman	121°47'	32°12'	110.57	51.6 x 50.9 x 33.9	2.432	5.4 x 5.4 x 4.2	156	36	20	
26	Round	c.3 km E. of Brookton	117°02'	32°22'	109.79	50.4 x 50.0 x 34.5	2.436	5.8 diam.	248	56	38	Baker (1967)
27	Round	Eastern Goldfields of W.A.	117°02'	32°22'	108.30	52.4 x 50.5 x 33.9	2.437	5.4 x 5.4 x 4.4	164	34	23	
28	Narrow oval	c.42 km E. of Narenbeen	118°50'	32°04'	107.457	65.3 x 38.9 x 32.9	2.431	7.3 x 4 x 4	149	28	22	Baker (1967)
29	Round	c. 11 km S.E. of Salmon Gums	121°44'	33°03'	102.37	46.4 x 44.6 x 38.0	2.426	5.2 diam.	179	43	37	
30	Broad oval	c.10 km W. of Kurnalpi	122°09'	30°28'	101.12	54.7 x 43.8 x 32.3	2.445	7.5 x 5.7 x 5.7	312	67	43	
31	Broad oval	Karonie	122°28'	30°58'	100.80	49.3 x 47.1 x 34.9	2.432	6.3 x 6.1 x 6.1	298	66	43	
32	Broad oval	Jubuk	117°41'	32°21'	(> 100) 86.80	(c.53) 47 x 49.1 x > 33.8	2.427	6.3 x 6.1 x 6.1	298	66	43	

The dimensions of a spherical primary body are stated by the diameter; for a prolate spheroid, dimensions are in the form 6 x 4 x 4 cm and for an oblate spheroid, in the form 6 x 6 x 4 cm (Table 2, col. 9).

From the dimensions of the primary body as determined above and on the not inconsiderable assumption of mathematically perfect form, the volume was calculated. The present volume had been determined incidentally to the measurement of specific gravity. The total percentage loss could thus be calculated. With the further assumption that the primary body had the same specific gravity as the remnant core, the percentage loss of volume is also the percentage loss of mass. The total thickness loss from the primary body was calculated from a consideration of the thicknesses of the primary body and the remnant core.

Total losses from the primary body include those of fusion and ablation stripping during flight, spallation of the stress shell, terrestrial losses as the result of both chemical and physical processes, and the artificial damage of some specimens.

Losses as a result of certain terrestrial processes such as chemical etching by soil water and biochemical etching by plant roots and hyphal filaments cannot be estimated quantitatively. It is believed that such losses will not generally exceed a few percent if expressed as

a percentage of the primary body and will usually be of a smaller order of magnitude than flight losses.

The losses, whether natural or artificial, of flakes which transect the otherwise smooth form of a core can be reasonably estimated by completing the form with modelling clay and converting the added mass of the clay to that of the same volume of glass. This was done wherever possible and the natural flake losses subtracted from total losses. Restoration of artificial losses, which are characterised by the brilliant lustre of the exposed glass, enabled estimation of the mass of an artificially damaged specimen when found. The restored mass of an artificially damaged specimen is shown in brackets immediately preceding the existing mass (Table 2, col. 6); likewise a restored dimension immediately precedes the existing dimension (col. 7).

The loss figures given in Table 2 cols. 11 and 12 are thus essentially those arising from atmospheric flight or its aftermath (stress shell) but including also terrestrial losses which have been minimised by allowance for natural flake losses.

Australite primary bodies had a complex internal flow structure, the schlieren differing slightly in their chemistry; they also contained bubble cavities of various sizes and of irregular distribution. Arising partly from the consolidation of the initially molten primary body and

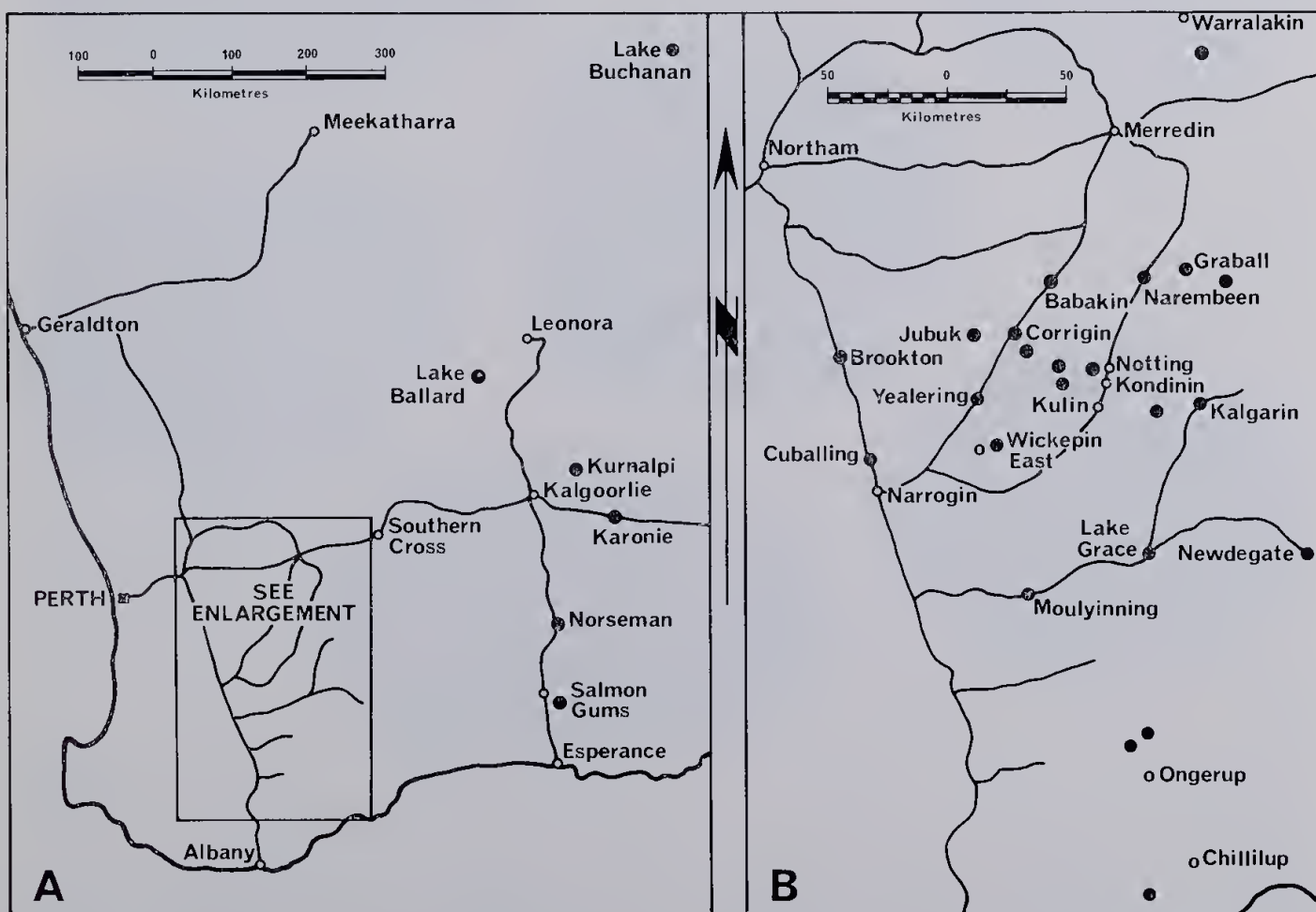


Figure 1.—A.—Sketch map of the south western part of Western Australia showing sites of find of australites of mass greater than 100 grams (solid circles.) in relation to some railway lines. B.—Enlarged portion of the same. The sites of Nos. 7, 14 and 27 (Table 2) are omitted for lack of sufficiently specific information.

from its heterogeneity, partly from stresses imposed by atmospheric transit and perhaps also by terrestrial processes, australites retain various degrees of residual strain. Terrestrial processes developed a variety of minor surface sculptural effects such as gutters (for details see Baker 1959) which often reflect these internal heterogeneities and strains. The minor sculpture developed on some specimens was partially removed during a later episode of transport or exposure to blown sand. Other specimens which had been abraded became buried and were subsequently chemically etched by the constituents of soil water. The better preserved specimens show minor features of the posterior surface such as flow swirls (Fig. 3-12) which were probably original features of the primary body, now accentuated by minor degrees of etching. Only the more prominent surface and sculptural features are noted in the descriptive section below.

Descriptive Notes

This section should be read in conjunction with Table 2 which shows physical data of the specimens. Figure 1, showing sites of find, if specifically known, should also be consulted. The abbreviations W.A.M., S.A.M., and W.A.S.M. refer to accession numbers in the collections of the Western Australian Museum (Perth), South Australian Museum (Adelaide) and the W.A. School of Mines (Kalgoorlie) respectively. Descriptions follow in the number sequence of Table 2, col. 1.

1. Fig. 2. Cast: W.A.M. 13238. The original is owned by Mr. P. Repacholi, who found it in 1969 whilst ploughing to a depth of c. 15 cm in the N.E. corner of Avon Location 15085, about 3 km W. of Notting railway siding. It is the most massive australite known.

The form is much modified by natural flake losses which have removed the rim except for a 5 cm length along one side and a 1 cm length elsewhere. Resulting also from flake losses the posterior surface is less symmetrical than the anterior. Surface dating from the time of arrival on the earth's surface is considerably weathered, the sculpture comprising pits of 1-2 mm diameter transitional through oval pits into short gutters, and larger composite pits which contain two or three oval pits within them. Longer gutters are restricted to remnants of the equatorial zone where they are oriented approximately parallel to the flight path and to three larger flake scars in that zone where they are oriented approximately parallel to the rim. The largest and most recent flake loss has removed much of one end of the core and the scar is characterised by circular and lunate bruise marks and is dulled by abrasion. Artificial damage comprises a 2 cm trail of millimetre sized scars, perhaps attributable to contact with the plough.

The transverse curvature of the posterior surface can be reasonably estimated, but calculation of the elliptical longitudinal section had to be based principally upon a 5 cm length of pitted surface. Natural flake losses are equivalent

to c. 3.5% of the mass of the primary body.

2. W.A.S.M. 8925. For a detailed description and illustrations of this specimen from near Warralakin, see Baker (1962).

3. Fig. 2. W.A.M. 12318. Found near Newdegate. Briefly described by McCall (1965) with illustration of the anterior surface. The form is sub-spherical (thickness/mean diameter ratio 0.91). No rim nor defined equatorial zone is present but there is a central girdle up to 2 cm wide characterised by a complex of gutters. The posterior surface has some patches of short gutters. The anterior surface, which is rather irregular, has some roughly circumferential gutters surrounding a complex of short gutters. The precise flight orientation, and hence the dimensions as conventionally stated, are in some degree a matter of opinion. Arcs of circles fit reasonably well the profiles of the posterior surface.

4. Fig. 2. Found by Mr. H. Biggin in 1940 or 1941 in the N.E. Corner of Avon Location 19835, about 14 km W. of Kondinin. Owned by Mrs. H. Biggin of "Karingal", Kondinin.

The specimen is fairly well preserved except for shallow natural flake losses from the posterior surface resulting in a tapered appearance in cross section. The longitudinal profile is not so badly affected and a reasonable estimate of the primary form is possible. There have been no artificial losses. The posterior surface, which is somewhat dulled by abrasion, has some circular and lunate scars and etched flow swirls. The equatorial zone is reasonably defined and has some short gutters, variously oriented. The anterior surface is asymmetrical in cross section and has composite pits containing short gutters and circular and lunate etched scars. Some of the gutters tend to be circumferential near the periphery. This surface is much like that of No. 1 which was found only 11 km distant.

5. W.A.M. 4455. Found on Lake Yealering which adjoins the Yealering townsite. Some details and illustrations of both surfaces were given by Fenner (1955), who noted the deeply pitted posterior surface and the unusual degree of development of gutters on the anterior surface (his Pl.VII Figs, 2, 1 respectively). Four views were figured by Chapman (1964, Figs. 6A, 7), who noted that gutters had been developed selectively on the surface exposed by loss of the striae shell. The diameter of 67.4 ± 0.5 mm is the largest for any known round core.

6. Owned by Mr. L. P. Berryman, who found it on Lake Ballard in 1968. Described and figured by Cleverly (1971).

7. Fig. 2. W.A.M. 12992. Found by an aborigine about 1920 and given to Mrs. C. Parrot; donated to the W.A. Museum by Mr. G. Woodland in 1969, by which time it was uncertain whether the site of find had been Narrogin or Narembreen (Fig. 1B).

Extensive but shallow flakes have been artificially struck from posterior and anterior surfaces, and an earlier, natural flake loss has removed the rim from around one end of the



Figure 2.—Australlites from Western Australia numbered as in text and Table 2. In all elevational views the anterior surface is towards bottom of page. 1a.—Posterior surface. Length 83.7 mm. 1b.—Anterior surface. 1c.—Side elevation showing greater regularity of anterior than posterior surface. 1d.—End elevation. Width 54.5 mm. 3.—Elevation showing angularity at upper left is the result of natural flake loss. Width c.60 mm. 4.—Side elevation. Length 64.8 mm. 7.—Side elevation. Length 67 mm. 9.—Elevation showing wedged anterior profile. Width 55.6 mm. 12.—Side elevation. Width 59.9 mm.

specimen. The posterior surface has unusual pits containing narrow, parallel or divergent, short gutters developed on bundles of more etchable schlieren. The remaining rim is reasonably defined and regular. The equatorial zone has some short gutters oriented normal to the rim and also a patch of deep pitting. The anterior surface has some pits transitional into short gutters.

Because of artificial damage, the form of the primary body can be assessed only very approximately. It is possible that the transverse profile was elliptical i.e. that the primary form was triaxial; if so the mass and percentage losses have been overestimated.

8. W.A.M. 12884. Found about 18 km W. of Notting railway siding. The lustre is dulled by abrasion. This is one of the few specimens examined which tends to bulge slightly anterior to the rim. The posterior surface has some lunate scars and small pits. The equatorial zone, which averages 15 mm wide, has abundant gutters which are variable both in orientation and form (some parallel to flight path, others vermiform or branching). The anterior surface has some gutters and bruise scars shallowed by abrasion.

Arcs of circles do not fit closely the profiles of the posterior surface and have radii in the range 3.1-3.3 centimetres. Because of these uncertainties, a mean figure was used to calculate the primary body as a sphere.

9. W.A.M. 12993. Turned up by a bulldozer from shallow depth in sandy soil about 19 km N. of Ongerup in 1968. This specimen has much the same form and unusual features as No. 3 above. There is no rim or defined limit to the equatorial zone but there is a band of distinctive sculpture. The posterior surface is somewhat irregular as the result of flake losses and has an area of deep pitting. Gutters are present only on the anterior surface with a suggestion of circumferential pattern. The anterior surface is strongly wedged (Fig. 2), thus presenting very different profiles when viewed from different directions. Arcs of circles fit profiles of the posterior surface fairly well and continue to fit over parts of the "equatorial zone".

10. Geological Survey of W.A. R.2024. Found near Cuballing. Described in detail and figured by Baker (1966) prior to its donation to the Survey collection.

11. W.A.M. 12843. Found at Graball, E. of Naremben. Described and figured by Baker (1963) prior to its donation to the Western Australian Museum. Because the percentage mass loss is the highest for any of these large cores, derivation from an oblate spheroid is suspected and this is supported by lens measure readings. However, because of the extensive etching and minor artificial damage to the posterior surface, no re-estimation of the primary body on that basis has been attempted.

12. Figs. 2 & 3. W.A. Government Chemical Laboratories Mineral Division collection 1678. Found about 5 km S.E. of Corrigin in 1955. The posterior surface is relatively well preserved and

shows minor sculpture ranging from barely perceptible schlieren through distinctly etched flow swirls to short gutters and a single elongate gutter paralleling the pattern of a flow swirl. The rim is reasonably defined and regular except where affected by minor flake losses and the development of an area of deep pitting. The equatorial zone has some gutters oriented normal to the rim; its limit is ill-defined. The anterior surface is distinctly wedged and shows a few gutters.

13. Cast W.A.M. 13237. Original owned by Mr. R. Kirkpatrick, who found it on Mr. C. Adams' property "Marambeena", c. 25 km S.W. of Chililup in 1972.

Neither the rim nor the anterior limit of the equatorial zone is clearly defined. The form of the posterior surface is considerably modified by the natural loss of small flakes. The equatorial zone is c. 10-18 mm wide and the minor sculpture is principally short gutters, variously oriented. The anterior surface is roundly and asymmetrically wedged parallel to the longer diameter. The low specific gravity (2.410) is probably to be ascribed to bubble cavities. The arc of a circle will fit well only to the transverse profile and the radius of that arc has been used in calculating the primary body as a sphere.

14. W.A.M. G8978, Described by Simpson (1939) with two unspecified views, the first an elevation with anterior surface towards top of page, the second the (presumed) anterior surface showing artificial damage. Bowley (1945) concluded that the specimen had been found between Narrogin and Merredin (Fig. 1) and this is feasible because several unusually massive australites have since been found within that general area.

15. In Geological Survey of W.A. collection. Found about 16 km N.W. of Ongerup. Fully described and figured by Baker (1967).

16. Found near Kalgarin in 1960. The finder shattered the core by a heavy blow with a hammer. The larger pieces were given to Mr. R. Pugh, who re-assembled them, but clearly many small fragments were not recovered.

Dismemberment disclosed a breached bubble cavity 6 mm diameter located just off the axial line and slightly closer to the posterior than to the anterior surface. Another cavity 2 mm diameter and a few smaller ones were also revealed. Fragments macroscopically free of fractures were selected for determination of specific gravity, the choice being thereby limited to three pieces of total mass 12.5 grams. The specific gravities are in the range 2.435-2.442 with a weighted mean 2.439. These fragments constitute only about 10% of the material, and because of exposure of bubble cavities, the specific gravity is biased towards the higher value for australite glass rather than representative of the australite as a whole.

The reassembled specimen is sub-spherical (mean diameter/thickness 0.93) with a defined but rather sinuous rim and equatorial zone. The posterior surface has a meridional strip from rim to rim containing short transverse gutters.



Figure 3.—Australites from Western Australia numbered as in text and Table 2. In all elevational views the anterior surface is towards bottom of page. 12.—Posterior surface showing etched flow swirls. Diameter 56.9–55.8 mm. 17.—Elevation showing well defined equatorial zone with gutters and natural flake loss from posterior pole. Width c. 53.5 mm. 19.—Anterior surface with artificial damage at upper left and natural flake loss from rim at lower edge. Length 79.6 mm. 21.—Side elevation. Central area is artificially abraded. Width 51.4 mm. 22a.—Anterior surface. Length 61.3 mm. 22b.—Side elevation showing area of deep etching affecting the posterior profile. 23.—Elevation showing globular form. Thickness 43.6 mm. 26.—Side elevation. Length 50.4 mm. 30.—Side elevation. Length 54.7 mm.

The equatorial zone also has gutters, some of which are meandrine. Because of the history of this specimen, all quantitative estimates of the core and its primary body should be regarded as very approximate.

17. Fig. 3. W.A.M. 3491. Found near Corrigin. Fenner (1934, 1955) made brief references to this specimen, in the second publication under the incorrect accession number 3441. Chapman (1964, Fig. 11) illustrated a side elevation chosen to emphasise the degree of imperfection (flake losses from posterior pole and rim and an extensive area of deep pitting) when compared with cores from elsewhere. The rim is fairly well preserved and regular. The posterior surface has some circular groove structures and some roughly circumferential gutters near the periphery. The equatorial zone has gutters oriented approximately normal to the rim. On the anterior surface, short gutters near the equatorial zone are oriented more or less circumferentially. Except in areas of imperfection noted above, arcs of circles fit fairly well the profiles of the posterior surface.

18. Australian Museum, Sydney DR:7533. Found at Lake Grace. The form is extremely irregular and asymmetrical as the result of natural flake losses from both posterior and anterior surfaces, and artificial losses caused by a severe blow on the posterior pole of the specimen. The rim is represented only by worn remnants and the limit of the equatorial zone is poorly defined. Short gutters, variously oriented, are present on the equatorial zone. A complex of oval pits and short gutters is present on the major anterior flake scar. The specific gravity is well below average for large cores from Western Australia. No reliable estimate of the primary body is possible.

19. Fig. 3. W.A.M. 12264. Found about 26 km E. of Kulin in 1960. The dull posterior surface contrasts with the "lacquered" appearance elsewhere. Some circular and lunate scars and two small areas of gutters on the posterior surface have been shallowed by abrasion. The rim is ill-defined and sinuous and there is no distinct anterior limit to the equatorial zone, though gutters show the usual orientation approximately normal to the rim. A reasonable estimate of the parental form is possible.

20. W.A.M. 12960 (formerly Geological Survey of W.A. collection 11177). Salient details and an illustration of the anterior surface were given by Simpson (1902, p. 81 and Pl.I), who described the site of find as being "100 miles East by South of Weld Springs, or say about Lat. 25° 30' S, and Long. 123° 0' E.", a point closely coincident with Lake Buchanan. The W.A. Museum catalogue records that the specimen was found by the Calvert Expedition of 1896-7. The presumed year of find was 1896 because Lake Buchanan was named by Surveyor L.A. Wells of the Calvert Expedition in that year (pers. comm. from W.A. Surveyor General's Department). An oblique view emphasising the posterior surface was figured by Thorp (1914 Pl. XVIII Fig. 6), who added incorrectly that the specimen was found at Weld Springs by the

explorer John Forrest; Fenner (1934) repeated the statement regarding the finder. Forrest was not associated with either the Calvert Expedition or the subsequent relief and search efforts; he had named The Weld Spring 22 years previously.

The fore-going is given in some detail to emphasise that the place and circumstances of find of this core are well authenticated. The site of find should not be stated as "Weld Springs" (i.e. The Weld Spring); nor should Lake Buchanan be confused with Lake Buchan, which is more than 900 km distant to the south west.

The rim of the core is well defined but there is no distinct limit to the equatorial zone. The posterior surface, where not affected by extensive but shallow artificial flake loss, has some circular pits transitional to circular gutters set in a surface of small scale "hammered metal" appearance. The anterior surface is much like the posterior but with the etching rather more advanced.

21. Fig. 3. S.A.M. T191. Fenner (1955) reported briefly on this specimen. Despite the fairly bright lustre, the core appears to have suffered considerable physical erosion. Small natural flake losses, an extensive but shallow artificial flake loss, and artificial abrasion of a small area on the equatorial zone have further contributed to the general irregularity and imperfection of the form. No rim is present and the assumed orientation depends partly upon the greater degree of asymmetry and the more abundant gutters on that surface chosen as anterior. Gutters, variously oriented, are also present on the equatorial zone and on the periphery of the posterior surface. Estimates of the form of the primary body with any reasonable degree of reliability are not possible.

22. Fig. 3. Owned by Mr. F. Davis, who found it on Avon Location 7501 about 8 km E.N.E. of Wickepin East.

The lustre is somewhat dulled by abrasion. The rim is irregular and poorly defined as is also the anterior limit of the equatorial zone. Etched strips on the posterior surface contain short gutters, mostly transverse to the length of the strips. Gutters on the equatorial zone are oriented at right angles to the rim and others outline the bottoms of oval flake scars. The anterior surface has a few gutters, etched schlieren and pits. The transverse profile of the posterior surface is symmetrically wedged as the result of natural flake losses (c. 8 g) and the longitudinal profile is also affected by flake loss. The estimates of the primary body are therefore very approximate.

23. Fig. 3. Geological Survey of W.A. collection 1/5327. Found at Narembreen. This core is closely equidimensional, having a thickness/mean diameter ratio of 0.95. The posterior surface has a complex of small gutters in depressed, deeply etched areas and other gutters tend to be circumferential near the rim. The rim is well defined. Minor sculpture of the equatorial zone is principally gutters, variously oriented. The anterior surface is asymmetrically wedged and

has some small gutters with tendency to circumferential orientation. Gutters are more abundant on the posterior than on the anterior surface, an unusual occurrence. The form of the primary body cannot be determined reliably because of the deep etching of the posterior surface.

24. W.A.M. 10613. The posterior surface and equatorial zone are similar to those of No. 21 above. The anterior surface has abundant gutters and a minor artificial flake scar. Most gutters are sharply defined and all are narrow (c. 0.2 mm). The forms of the longitudinal and transverse profiles had to be estimated from surviving patches of original surface and the results differed by 2 millimetres. The parent mass might have been a slightly prolate spheroid but has been calculated as a sphere using the mean figure as radius.

25. S.A.M. T427. Initially in the collection of Mr. S. F. C. Cook. Fenner (1934, 1955) made brief references to this specimen from Norseman and illustrated the posterior surface. Little can be added because of the extremely corroded state of the specimen. As is well shown by Fenner (1934 Pl. IX E2), the posterior surface lost a flake from the polar area and subsequently developed such a degree of pitting as to approach the appearance of hammered metal. Such sculpture with patches of interrupted, etched schlieren extends over the entire surface. The rim and the limit of an equatorial zone c. 1 cm wide are still recognisable and within the equatorial zone are modified flake scars. The form of the primary body must needs be judged by that of the annular and much corroded remnant of posterior surface.

26. Fig. 3. W.A.M. 12090. Found by Mr. F. Basset about 3 km E. of Brookton in 1961. The form is somewhat irregular as the result of minor flake losses. The posterior surface has a narrow band running obliquely from rim to rim containing short gutters and terminating in deeply pitted areas at each end. The rim and the limit of the equatorial zone c. 1 cm wide are poorly defined. The equatorial zone has gutters oriented normal to the rim and outlining the bottoms of oval flake scars. The anterior surface is distinctly asymmetrical in profile; its central area has a complex of short gutters. Flake losses could not be assessed with confidence but the percentage represented would be small.

27. W.A.S.M. 10199. This australite from an unspecified locality in the Eastern Goldfields of Western Australia has been described by Baker (1967). Additionally, an assessment of the primary body has been attempted.

28. W.A.S.M. 8950. For detailed description and illustrations of this specimen from 42 km E. of Narembene, see Baker (1961). Because of the deeply corroded condition of this core the estimate of the form of the primary body is very approximate.

29. W.A.S.M. 9421. Found by Mr. J. P. Parker about 11 km S.E. of Salmon Gums in 1962. Described by Baker (1967). An estimate of the form of the primary body has been attempted.

30. Fig. 3. Owned by Mr. C. B. C. Jones of Hampton Hill Pastoral Station. Found on the station about 10 km W. of the abandoned Kurnalpi townsite. This specimen evidently suffered some wear in transport before enclosure in alluvium because natural flake scars are well rounded yet the entire surface now has a uniformly bright lustre. There has been no artificial damage. Natural flaking has removed a continuous length of half the rim; the remainder is well defined and regular as is also the limit of the equatorial zone. Both posterior and anterior surfaces have etched lunate and circular bruise scars. The equatorial zone has a few gutters oriented normal to the rim and etched flake scars. A fair estimate of the primary body is possible; flakes account for only about 1% loss.

31. S.A.M. T509. Formerly in the collection of Mr. S. F. C. Cook. Illustrations of this specimen given by Fenner (1955) include an elevational view showing the sharp, well-preserved rim (Pl. VIII-16). The surface has a bright lustre. The rim is complete except for a minor natural flake loss. The posterior surface has some short gutters with tapered ends and V-shaped cross sections reminiscent of gash fractures and they tend to radial orientation. The Lake Ballard core (No. 6, Table 2) is the only other of these large Western Australian specimens having such gutters on the posterior surface, but their development is much further advanced in that example (Cleverly 1971 Fig. 1). The equatorial zone has well-defined gutters of U-shaped section oriented normal to the rim. The anterior surface is almost free of minor sculpture.

32. W.A.M. G7566. This fragment is included for completeness of record. The entire anterior surface and one end have been removed by artificial fracture. The bluntly wedged remnant has angle c. 115° and by analogy with other artificially broken specimens the edge was probably immediately beneath the anterior surface as found. Reconstruction suggests that the mass prior to artificial fracture certainly exceeded 100 g, and possibly attained 115 grams. The dull abraded remnant of posterior surface has small depressed areas containing narrow gutters and small areas of deep pitting extending to the equatorial zone, the remnant of which has some gutters oriented normal to the rim.

Round core of unknown provenance

Fenner (1955) figured the artificially damaged posterior surface and a side elevation (Pl. VII Figs 5 and 6 respectively) and stated that the specimen had been found in the Western Australian Goldfields. The owner, Miss K. D. Blackham of Adelaide, is insistent that neither the finder nor site of find is known to her; the specimen might have come from any of the gold mining localities with which members of the family had early associations, viz. Ballarat (Victoria), Teetulp (South Australia), Coolgardie and Kalgoorlie (Western Australia).

The dimensions are 52.7 x (51.3)51 x 44.5 mm, the mass 153.96 g (c. 168 g prior to artificial damage), and the specific gravity 2.399. The specific gravity is distinctly lower than that of

any other australite of mass exceeding 100 g for which values are available. The figure is much closer to average values in Victoria than those elsewhere (Baker 1969 Fig. 2), but the value for an individual australite has very limited significance. Although 2.399 is almost the mean value for Port Campbell, Victoria specimens, it nevertheless lies within the range shown by australites from the Kalgoorlie district, Western Australia (Chapman *et al.* 1964 Fig. 7). The general aspect of the specimen is that of a water worn pebble. The entire surface is dulled by abrasion and the bruise scars show various degrees of freshness or of shallowing by abrasion. Possibly only one episode of transport with intermittent bruising is represented.

No clear indication of provenance was recognised but an area in which true alluvial gravels existed (i.e. Victoria or possibly Teetulpa) seems rather more likely than arid interior Western Australia. Victoria is the more likely because the known area of occurrence of unusually massive australites (Baker 1969) overlaps the alluvial goldfields; Teetulpa is nearly 300 km distant from the Karoonda-Lowaldie area, from which have come the only two cores of mass exceeding 100 g yet reported from South Australia.

Discussion

The Lake Buchanan core (No. 20) was the first recorded australite of mass exceeding 100 grams (Simpson 1902). The number of such specimens known grew slowly to 24 (Baker 1972). The present known total is 41, comprising 32 from Western Australia (Table 2), six from Victoria (Baker 1969, 1972), two from South Australia (Fenner 1955) and one of unknown provenance (this paper). Most of the recent increase is accountable to previously unpublished specimens in the W.A. Museum collection and to specimens which are privately owned. An australite said to have been found in the vicinity of Eucla and of mass c.142 g (Fenner 1934 p. 78) has not been included in the total because the report is hearsay only, though the locality would fit well the distribution pattern referred to below.

The number of additional specimens in private hands is unknown but probably considerable to judge by the response to some very limited publicity. A brief news item submitted to a Kalgoorlie radio station concerning the discovery of the 437 g (No. 1) specimen, had the immediate result that No. 16 was offered for examination; an article on australites published for the writer by the *Narrogin Observer* brought in response Nos. 4 and 22.

The sites of find of the Western Australian specimens (Fig. 1) comprise a south west group and scattered occurrences to the east and north east. The south west group lies entirely within the main wheat belt, where there is a settled population and where the land is periodically seen and shallowly embedded objects are brought to the surface during cultivation. To the immediate east of this belt, both north and south of the principal Perth-Kalgoorlie road and rail links, there is no permanent settlement and a corresponding gap in the distribution pattern.

Further east again is the narrow strip of country containing a few widely spaced centres of population associated with mining in the north and agriculture in the south (Salmon Gums). The two most northerly australites were chance discoveries of a mineral exploration party outside the active mining area and of an exploration expedition in country which is still on the extreme fringe of extensive-type pastoral development more than seventy years later. There is thus such a close positive correlation between the sites of find and the distribution of human activities that it is tempting to dismiss the first distribution as a direct result of the second. However, there is good evidence, at least for the Eastern Goldfields region, that australites of mass exceeding 100 g are extremely rare.

The most important evidence is the private collection of Mr. D. L. Tillotson containing nearly 11 000 located australites gathered from a broad belt extending up to 200 km north and south from Kalgoorlie; the most massive specimen in this collection is of only 58.1 grams. The C. B. C. Jones family collection has been gathered from the country immediately E.N.E. from Kalgoorlie and is numerically at least equal to that of Mr. Tillotson; the most massive specimen is of 101.12 grams (No. 30 this paper). The Cook collection of more than 5 000 specimens, now in the South Australian Museum (Fenner 1949), was gathered from a more extensive area also centred upon Kalgoorlie; only two specimens (Nos. 25, 31) qualified for inclusion in this paper. Smaller official and private collections could also be cited as well as the thousands of australites which pass through the hands of commercial lapidaries. The most massive of about 5 000 specimens handled by one Kalgoorlie lapidary in recent years has mass 59.1 grams. This general region has twice been intensively prospected, earlier for gold and latterly for base metals. Inclusive of the numerous small private collections resulting from these activities it is likely that 40 000 australites have been recovered from the Eastern Goldfields, yet only six are known of mass exceeding 100 grams.

Further to the north, Earacheedy and other pastoral stations to the west and south-west of Lake Buchanan are represented in available collections by more than 1 300 specimens of which the most massive is a 74.2 g specimen from Wongawol (No. 22 in E. S. Simpson collection held at W.A. Museum).

The Western Australian wheat belt extends a further 400 km north-westerly from the australite occurrences shown in Fig. 1B, presumably with equally good opportunities for observation of australites, yet no specimen of mass exceeding 100 grams is known to have been recovered there. The centering of the infall of unusually massive australites in the south west of Western Australia thus appears to be a reality, but the area of their occurrence is almost certainly larger than is shown in Fig. 1B, the eastern boundary having resulted from the circumstances of collection.

The coastal strip flanking the wheat belt to the west and south was omitted from consideration above. It has relatively high rainfall and

much of it is heavily timbered. Though it has the highest density of human population for any part of the State, it is poorly represented in australite collections. This paucity of known australites is likely to be, at least partially, the consequence of an adequate drainage and vegetation cover when compared with the extensive cultivated areas and bare, semi-arid terrain further inland.

An almost cylindrical australite fragment (W.A.M. 13202) of mass 42 g from the Albany district (Fig. 1A) is the central portion of a stout-waisted dumbbell; the width and thickness at the waist are 29.2 mm and 27.2 mm. The analogous dimensions of the 151 g Ongerup dumbbell are 33.2 mm and 26.8 mm (Baker 1967). It is thus likely that the fragment represents an australite of which the mass attained 100 g, so that the area of infall of unusually massive specimens should be extended to the south coast.

Knowledge of australite distribution is very imperfect and the number of specimens concerned in the present paper is very small. Extreme caution is therefore necessary before acknowledging the existence of a pattern in the distribution and the following is offered with some diffidence.

The six Western Australian australites of mass exceeding 200 g were found in a belt extending S.S.W. from Lake Ballard, i.e., in a direction approximately at right angles to the northern boundary of the australite strewnfield (Baker 1969b Fig. 1). When the distribution of the most massive specimens of other mainland states is also considered (Baker *op. cit.*) the sites are seen to occur in areas distant from that boundary, the south western portion of the continent being the most distant and extensive and containing the sites of 17 of the 20 most massive australites known. These observations suggest the possibility of a mass grading away from the strewnfield boundary. If the direction of flight is to be related to such a grading, it is at variance with the conclusions of Baker (1969a), McColl and Williams (1970) and Chapman (1971). It would be of interest to know the distribution of a less massive category, say 50-100 g, and whether there are large overlaps in the distribution of successive categories as would suggest the entry into the atmosphere of a range of masses either continuously or at various points along a flight path. The greater numbers in the less massive categories should provide more reliable data.

The mean specific gravity of all 32 specimens under consideration has little significance because of the wide area of occurrence represented, but the more circumscribed south west group of 25 specimens warrants brief consideration. With the exception of Nos 2, 13 and 18, the low specific gravities of which are probably attributable to bubble cavities, specimens of this group have specific gravities in the narrow range 2.420-2.439, a variation of less than 1%. This degree of constancy might suggest a distinct population within the australite shower but another explanation is more probable. The heterogeneity arising from irregular distribution of bubble cavities of various sizes in australite glass may be expected to be evident

in groups of small australites as a considerable variation in their specific gravities. For groups of increasing size from any one area, the amount of variation arising from this cause may be expected to decrease until the most massive specimens approximate to the bulk specific gravity of the material and only occasional specimens show significant departures from the mean value, i.e. the larger samples of a heterogeneous material are more likely to be truly representative. The constancy of values could thus arise from the large sizes of the specimens.

The weighted mean specific gravity of the 25 specimens in the south west group of total mass 4.2 kg is 2.427. This is a lower mean value than for other measured groups in Western Australia (Baker 1969b) but the group is located further south than the others. Because these large cores have lost stress shells and are generally quite eroded, they retain virtually no surface glass from which constituents could have been volatilized during atmospheric flight as occurs from flange glass. The low mean specific gravity cannot therefore be attributed to that cause.

Globular, more or less equidimensional cores are well represented in the south west group. They reach their extreme development in Nos. 3 and 9 which lack a rim. Other specimens (Nos. 8, 16, 23), though rimmed, have even higher thickness/diameter ratios and calculated losses are very low. After allowing for a stress shell, thickness losses of 4-9 mm leave little or nothing for ablation losses. It has to be conceded as a possibility that these cores, all of which are round or only slightly oval, developed from prolate spheroids which travelled with the long axes parallel to the flight paths. In calculating the primary bodies as spheres their primary masses would be underestimated and likewise the losses from them.

No detailed analysis of the loss figures has been attempted because the number of reliable estimates available for any one shape type is so small. The loss figures are generally low. The average volume loss is only 46% compared with 56.5% for 23 perfectly preserved buttons from Port Campbell, Victoria (Baker 1962), though the loss of a stress shell did not contribute at the latter locality and terrestrial losses were insignificant. In a very general way, the better preserved cores have the higher loss figures. There may therefore be errors not only in the estimated dimensions of the primary bodies but also in the shape types ascribed to them.

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Dr. George Baker of Melbourne kindly read the first typescript of this paper and it has been distinctly improved by the amendments which he suggested.

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11.—Annual *Medicago* species with particular reference to those occurring in Western Australia

by J. A. McComb¹

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Abstract

Thirteen species of annual *Medicago* are recorded from Australia, including Western Australia—*M. arabica*, *M. intertexta*, *M. laciniata*, *M. littoralis*, *M. lupulina*, *M. minima*, *M. orbicularis*, *M. polymorpha*, *M. praecox*, *M. rugosa*, *M. scutellata*, *M. tornata*, and *M. truncatula*. Ten species are naturalized, and from four species 10 cultivars have been developed. A summary of the main generic features is given, together with keys and descriptions for species identification.

Introduction

The annual species of *Medicago*, like many other inbreeding plants, may be very variable within species and so have many infraspecific taxa, but show parallel variation and marked similarities between species. These features have resulted in a confused taxonomy. The most recent comprehensive taxonomic work on annual *Medicago* is by Heyn (1963, 1970) who showed that well over one hundred specific epithets have been applied to the 28 annual species she includes. This paper is not a taxonomic revision, and Heyn's taxonomic treatment is applied to the Australian material. Further information on taxonomy and species descriptions is given by Urban (1873, 1877), Sinskaya (1950), Negre (1956, 1959), Bolton (1962), Willis (1972), Lesins and Gillies (1973), and Quinlivan *et al.* (1974). Descriptions of cultivars registered in Australia and of some naturalized species are available in Barnard (1969, 1972).

Medics have been introduced to Australia from the Mediterranean, and the forms found here do not always show the same range of characteristics described for the species as a whole, as in Heyn (1963). This paper describes the species found in Australia and provides keys for identification of either flowering plants or burrs alone. The descriptions are based on accessions from various parts of Australia, maintained in a living collection of some 650 accessions of annual medics at the University of Western Australia. The collection also includes examples of all annual species not naturalized in Australia (McComb 1971). For all species some lines have been validated either by C. Heyn (Hebrew University), or by K. Lesins (University of Alberta). Extensive field collections have been made in Western Australia and herbarium material examined at UWA and PERTH. The synonymy found in Australian literature is listed. Only a summary of the distribution in Western Australia is given; similar

information for other Australian states may be found in Amor (1966), Andrew and Hely (1960), and Barnard (1969).

In Australia the common name 'medic' (earlier medick) is restricted to the annual species while the perennials are called 'lucerne' or 'alfalfa'. In other countries the common names medic, lucerne, or alfalfa may be applied to either perennial or annual species (Bolton 1962). The annual medics are sometimes called 'yellow trefoils' but the name 'trefoil' is also used for *Trifolium* and *Lotus* species, so the term 'medic' is preferred.

Botanical description of the annual species

Habit and vegetative parts

Annual medics germinating in late autumn, form a rosette of leaves before producing branches from the crown. The branches, which do not root at the nodes, may be prostrate and up to 1 metre long, or semi-erect and form a diffuse plant up to 40 cm high. Growth forms and branch length depend largely on environmental conditions and whether the plants are isolated or growing in a sward. Such features are therefore variable and not particularly useful in species descriptions. The outline of the stems in transverse section, as used by Negre (1956) was found to be similarly variable and has not been included.

The leaves are trifoliolate and differ from those of clovers (other than hop clovers) in that the stalk of the central leaflet is longer than that of the laterals (i.e. leaves are pinnate rather than digitate). Leaves of seedlings of *M. arabica* and *M. lupulina* may have digitate leaves but all later leaves are pinnate. Leaflet shape is variable, even on the same plant; lower leaves are usually cuneate or obovate and those produced higher on the branches more oval. Leaf morphology and measurements given in the species descriptions are based on the central leaflets of the largest mature leaves. Stipules are only very shortly adnate to the petiole as compared with species of related genera *Trigonella*, *Melilotus* and *Trifolium*, and the stipule margin is serrate, incised, or lacinate, rarely entire. Vegetative parts may be glabrous (but provided with closely appressed, small glandular hairs with short stalks which are rarely noticed unless an epidermal peel is examined under the microscope) or hairy, with simple or articulated, glandular or non-glandular hairs.

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Flowers

The flowers may be solitary, or number to 10, while one species (*M. lupulina*) has up to 50 flowers per raceme. Flowers are shortly pedicellate, bracteate, in loose racemes on an axillary peduncle which in most species is produced into an awn beyond the terminal flower. The relative length of the peduncle when it bears open flowers, and the petiole of the subtending leaf, is used as a taxonomic character.

The calyx is tubular or campanulate with five equal, or subequal lobes. Petal morphology is shown in Fig. 1. The corolla is always yellow, but there are usually purple-brown stripes in the centre of the standard. The petals occasionally have a purple tinge at the tips in young buds, or in herbarium material. 'Flower length' in the species descriptions is the length of the standard which, ranging from 2-10 mm, is longer than the wing and keel petals in all species. The relative lengths of wing and keel petals is used as a taxonomic character (cf. Figs. 11A and 16L).

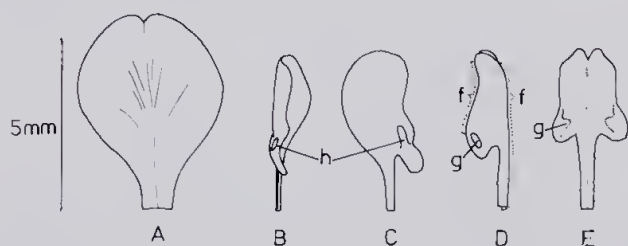


Figure 1.—Petal morphology in *Medicago truncatula*. A: Standard petal. B: edge view and C: inside view of wing petals showing the horn-like protrusion (h). D: side view and E: inside view of keel petals showing the fused edges (f) and the groove (g) into which the horn on the wing is inserted.

Nine of the ten anther filaments are fused into a sheath and one is free. Baum (1968) found that anther morphology may be used to separate the closely related genera *Medicago* and *Trigonella*. In *Medicago*, when the staminal sheath is opened out, it can be seen that the filaments arise from an arched apex, the bases of alternate filaments are swollen, and in the fused sheath there is some thickening along the vascular bundles of all, or at least the central three stamens. *Trigonella* shows two types of androecium, a 'simple' type in which the filaments emerge from a flat apex and no filaments are swollen at the base; and a 'medicagoid' type in which the filaments emerge from an arched apex, and filaments on either side of the central one have swollen bases. In neither the simple nor the medicagoid type is there any thickening around the vascular bundles. Observations on the medics which occur in Australia show that the anthers arise from an arched apex and that alternate bases are swollen, but these characters are much more strongly developed in some species (e.g. *M. truncatula* and *M. scutellata*) than in others (e.g. *M. polymorpha* and *M. minima*). In some forms of *M. lupulina* (which may also lack the 'tripping' mechanism—see below), the features are particularly poorly developed (Figure 2). The thickening

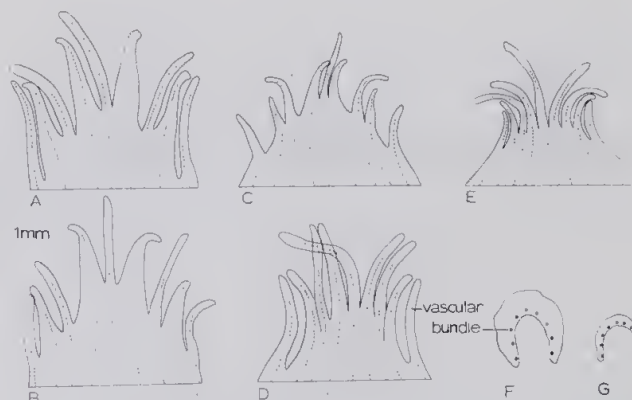


Figure 2.—Apical part of the 9 fused anther filaments in *Medicago* species. A: *M. truncatula*. B: *M. scutellata*. C: *M. polymorpha*. D: *M. minima*. E: *M. lupulina*. F: T. S. of fused filaments of *M. truncatula* and G: *M. lupulina*. (camera lucida drawings)

along the vascular bundles proved difficult to see and it is possible that the 'thickening' recorded by Baum using anther sheaths softened in lacto-phenol and flattened, results from the width of the sheath as seen in T.S. (Fig. 2).

The linear ovary has 1-28 ovules. The style which is subulate or filiform and has an oblique terminal stigma, may persist on the fruit but is never hardened into a rostrum as in *Trigonella*. The length of the floral bracts relative to the pedicel length and the calyx, as used by Negre (1956) was found to be too inconsistent, both within species and between flowers on the same plant, to be of taxonomic use.

Tripping mechanism

The flowers of the annuals are self fertile (with the possible exception of some *M. intertexta* (Lesins and Gillies 1973)), and largely self-pollinating. They lack nectaries (Heyn 1963) but are occasionally visited by insects. The perennial species have an elaborate 'tripping' mechanism for pollination which is an adaptation to cross fertilization by insects, and this tripping mechanism is retained in the annuals even though they are self pollinating. The mechanism is not found in the related genera *Trifolium*, *Trigonella* or *Melilotus*.

In the freshly-opened flower the anthers have dehisced but the pollen is contained by the surrounding keel petals. The style, surrounded by the anther filament sheath, is retained between the keel petals which are fused along their outer edges as well as for some distance along the edges facing the standard, but are free at the tips. The cohesion between keel petals results from interlocking projections on the epidermis (Larkin and Graumann 1954). The strength of the cohesion partly determines the ease with which the flower can be caused to trip. If the keel is touched so that the petals are split apart, the style and anthers are flung forward on to the standard petal. The wing petals which have horn-like protrusions appressed to grooves in the keel (Fig. 1), may be removed carefully without causing tripping, but usually movements of the wings are transmitted to the

keel and the style trips (Heszky 1972.). As the style trips a membrane is torn from the stigmatic surface making it receptive, and the pollen is pressed into the stigma (Armstrong and White 1935). The force with which the sexual column snaps over is determined by the structure of the region where the base of the fused anther filaments joins with the base of the keel petals (Larkin and Graumann 1954). When the flower has been tripped the anther filaments are curved and cannot be straightened without tearing the tissue. Non-tripped flowers do not set fruit. In the annuals self-tripping and consequently self-pollination are most common, although insects sometimes cause tripping. In countries where the species are native a low frequency of cross-pollination occurs and some species hybrids are found (Heyn 1963). In one species only, *M. lupulina*, are there some forms which lack the explosive tripping mechanism (Heyn 1963).

Fruit

The calyx is persistent, and in contrast to most clovers the corolla is deciduous. The developing coiled fruit may be contracted and concealed within the calyx (Fig. 16M); contracted but protruded sideways from the calyx (Fig. 11B); or it may hang from the calyx in a loose spiral and later become compact (Figs. 5B and 10A). These development types have been used for subgeneric divisions. One of the characteristics given by Heyn for the generic sub-sections *Rotatae* and *Pachyspirae* of the Section *Spirocarpos* 'young pods contracted and concealed within the calyx' was found to be invalid. In *M. scutellata* and *M. rugosa* the young pods protrude sideways from the calyx while in *M. littoralis*, *M. truncatula* and *M. tornata* coils could be concealed or protrude sideways in flowers on the same plant.

The mature fruit always exceeds the calyx in length and the number of pod coils ranges from 1-11. Fruits may be spiny or smooth and are indehiscent, but may gape open where the seeds are positioned. Much taxonomic weight is placed on the burr morphology and the arrangement of the radial veins on the surface of the burr, and the presence or absence of a submarginal or lateral vein along the dorsal suture (see Figs. 10B and 11F). This venation is sometimes obscure, but is best seen on the surface of a middle coil of a full size, but not fully hardened burr. Coiling direction, as determined by the direction of a line running from calyx to style, when the burr is held with the calyx end towards the observer, may be clockwise or anticlockwise. It may be typical of a species or both types may occur in the same species. In the *M. truncatula*, *M. littoralis* and *M. tornata* species group, coiling direction is controlled by a single gene, clockwise coiling being determined by the dominant allele (Simon 1965; Simon and Milington 1965). The dimensions of the burrs given in the species description are from dry mature burrs, which are smaller than freshly-picked green burrs. Measurements of diameter and height are of the coils without the spines.

Seeds

M. lupulina has only one seed, but other species have up to 28. Seeds are yellow or brown (black in *M. intertexta*), oval, kidney or horse-shoe shaped, and may be separated in the pod by false parenchymatous partitions. They are commonly impermeable, i.e. hard, when fully mature and dry. The seeds have strophioles (c.f. Hutchinson 1964) and it is usually in this region that cracks form and render the seed soft (Fig. 16K). Seed size usually decreases from the calyx to stylar end with often a small misshapen seed at the stylar end. Seed dimensions are based on average sized seeds.

Seedlings

The expanded cotyledons are oval or oblong-linear, the blade merging gradually into the stalk, in comparison with *Trigonella*, *Melilotus* and *Trifolium*, which have a distinct node between petiole and lamina (Fig. 3). This character is quite distinct, even though there is no difference in venation between the two types (Heyn 1968). However, I have been unable to confirm the observation that the base of the

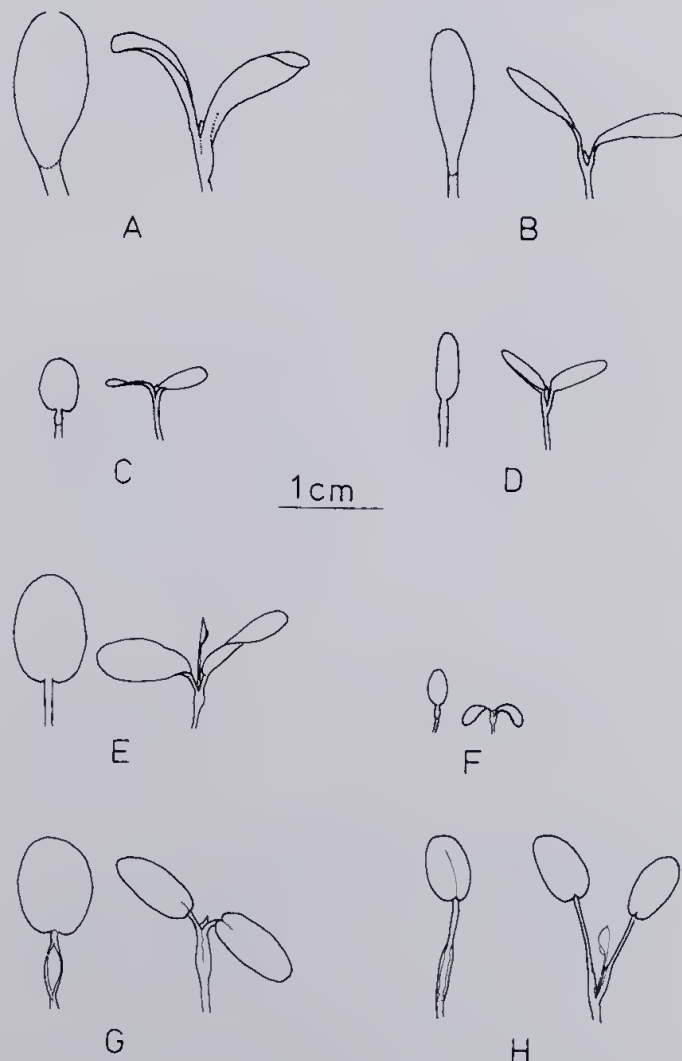


Figure 3.—Cotyledon morphology. A: *Medicago scutellata*. B: *M. polymorpha*. C: *Trigonella coerulescens*. D: *T. cylindracea*. E: *Melilotus italica*. F: *M. indica*. G: *Trifolium clypeatum*. H: *T. subterraneum*.

petiole is "swollen" in *Trigonella* and *Melilotus* and not in *Medicago* (Urban 1873, quoted in Baum 1968; figured in Heyn 1963 and 1970). Species from these genera which I have grown (36 *Medicago*; 9 *Melilotus*; 11 *Trigonella*; 11 *Trifolium* species) show no basal swellings, and at most a slight bulge due to the expansion of the plumule (Fig. 3). In *Trifolium* the bases of the petioles may be fused and bulge when they enclose the developing plumule, but the thickness of the stalk is not increased at the base. It suffices therefore to distinguish only between a gradual merging between lamina and petiole, and an articulation between the two. The seedlings produce a single unifoliate leaf, then trifoliate leaves.

Key to species based on mature burrs

(Species descriptions are listed alphabetically)

- | | | | |
|--|----|--|---|
| 1. Burrs spineless or with small tubercles | 2 | | |
| 1. Burrs spiny | 9 | | |
| 2. Burrs single-seeded, black, with distal end coiled | | <i>M. lupulina</i> | |
| 2. Burrs many seeded (rarely only one seed), coiled along full length | 3 | | |
| 3. Coils concave lower coils enclosing upper ones, burr cup- or olive-shaped | | <i>M. scutellata</i> | |
| 3. Coils not as above | 4 | | |
| 4. No membranous partition between seeds, burrs hairy | 5 | | |
| 4. With membranous partition between seeds, burrs glabrous or hairy | 6 | | |
| 5. Burr diameter 6-9 mm, central coils lozenge-shaped with raised veins on swollen outer margins, no lateral veins | | <i>M. rugosa</i> | |
| 5. Burr diameter 3-4½ mm, coils lenticular or discoid, lateral veins well separated from dorsal suture | | <i>M. minima</i> var. <i>brevispina</i> | |
| 6. No lateral veins, burr diameter 13-17 mm, margin of coils thin and membranous, seed coat rugose | | <i>M. orbicularis</i> | |
| 6. Lateral veins present, burr diameter less than 10 mm, edge of coil not thin and membranous, seed coat smooth | 7 | | |
| 7. No indentations between lateral vein and dorsal suture | | <i>M. tornata</i> var. <i>tornata</i> cv. <i>Tornafeld</i> and cv. <i>Murrayland</i> | |
| 7. With indentations between lateral vein and dorsal suture between bases of vestigial spines | 8 | | |
| 8. Lateral veins close to dorsal suture, groove narrow and deep, 15-20 strongly curved radial veins, burr 2½-8 mm high | | <i>M. polymorpha</i> var. <i>brevispina</i> | |
| 8. Groove wider and shallow (in part obliterated in very thickened burrs), about 10 radial veins almost straight, burr 6½-11 mm high | | <i>M. truncatula</i> cv. <i>Cyfield</i> and naturalized material | |
| 9. Burr coiling clockwise | | | <i>M. truncatula</i> cvs. <i>Cyprus</i> and <i>Hannaford</i> and naturalized material |
| 9. Burr coiling anticlockwise | 10 | | |
| 10. Burrs without partitions between seeds | 11 | | |
| 10. Burrs with partitions between seeds | 13 | | |
| 11. Seeds black, burrs 10-14 mm diameter, long entangled spines like a sea urchin | | | <i>M. intertexta</i> var. <i>intertexta</i> |
| 11. Seeds brown or yellow, burrs less than 7 mm diameter | 12 | | |
| 12. Burr 5-6 mm wide x 5-7 mm high, broad dorsal suture, radial veins entering lateral veins and a deep groove between lateral veins and dorsal suture | | | <i>M. laciniata</i> var. <i>laciniata</i> and var. <i>brachyacantha</i> |
| 12. Burr 3-5 mm wide x 2½-5 mm high dorsal suture narrow, radial veins enter lateral veins which are separated from dorsal suture by a broad margin (± ½ width of coil) across which run the veins to the spines | | | <i>M. minima</i> var. <i>minima</i> |
| 13. Coil edge with 3 grooves and 4 ridges (2 lateral furrows and a central furrow bisecting the dorsal suture); radial veins ± 8, radicle more than ½ as long as cotyledons | | | <i>M. arabica</i> |
| 13. Not as above | 14 | | |
| 14. Coils strongly appressed when mature | 15 | | |
| 14. Coils not strongly appressed | 17 | | |
| 15. Lateral veins in the same plane as the dorsal suture on the edge of the coil, no indentations between lateral veins and dorsal suture, burrs glabrous at maturity, spines long (up to 4 mm) inserted at 130° in middle coils, and 90° at apex. | | | <i>M. littoralis</i> var. <i>littoralis</i> |
| 15. Lateral veins on the surface of coil, indentations between lateral veins and dorsal suture between spines bases (especially when young, and seen in all but the most thickened burrs at maturity) | 16 | | |
| 16. Burrs 4½-10 mm high, 3-7 coils, spines 1-3 mm long, inserted at 120°-90°, burrs with scattered hairs. (pubescent when young) | | | <i>M. truncatula</i> cv. <i>Jemalong</i> , cv. <i>Borong</i> cv. <i>Ghor</i> and naturalized material |
| 16. Burrs, 2½-4 mm high, 3-4 coils, spines 1 mm or less, inserted at 90° to coil surface, burrs glabrous at maturity (sparsely hairy when young) | | | <i>M. littoralis</i> cv. <i>Harbinger</i> |
| 17. Dorsal suture region wide (± 1 mm), adjacent coils not in contact, wide spaces between coils, 10-15 spines per coil, a deep groove between dorsal suture and lateral veins which is seen from the surface rather than the edge of the coil | | | <i>M. praecox</i> |
| 17. Dorsal suture region thin (± ½ mm), coils in loose contact, 15-20 spines per coil, groove between dorsal suture and lateral vein clearly seen on viewing coil edge-on | | | <i>M. polymorpha</i> var. <i>vulgaris</i> |

Key to species based on flowering plants without mature burrs

1. Flowers 10-50, peduncle more than 2x the petiole of subtending leaf *M. lupulina*
1. Flowers 1-10 (rarely — 15 in *M. tornata*) peduncle at most 2x the petiole of subtending leaf 2
2. Upper surface of leaves glabrous (check on young leaves) lower surface glabrous-densely hairy 3
2. Upper surface of leaves densely hairy, or with at least sparse hairs when young, lower surface moderately-densely hairy 9
3. Dense glandular and non-glandular hairs on lower side of leaf and elsewhere 4
3. Not as above 5
4. Standard 6-7 mm long 1-2(3) flowers, upper side of stipules glabrous or with rare glandular hairs *M. rugosa*
4. Standard 6-7 mm long 1-3(3) flowers, upper side of stipules with dense glandular hairs *M. scutellata*
5. Young fruit in long spiral sideways from calyx contracting later, leaves with purple shield-shaped mark *M. intertexta*
5. Young fruit in contracted spiral sideways from calyx; no leaf mark, or different to the above 6
6. Leaf mark an upper central blotch or a very wide shield and occupying the basal $\frac{2}{3}$ of the leaf, articulated hairs on vegetative parts *M. arabica*
6. Leaf mark none or not as above, simple hairs on vegetative parts 7
7. Leaves oblanceolate, possibly some leaves lacinate *M. laciniata*
7. Leaves cuneate or obovate, margin entire or dentate 8
8. Leaves 8-27 mm long, 7-19 mm wide standard 3-6 mm long, wings longer than keel *M. polymorpha*
8. Leaves 7-9 mm long, 5-7 mm wide, standard 2-3 mm long, wings shorter than keel *M. praecox*
9. Stipules entire or weakly dentate, both surfaces hairy *M. minima*
9. Stipules dentate or incised, upper surface glabrous 10
10. Young fruit protruding sideways from calyx in long spiral, contracting later *M. orbicularis*
10. Young fruit contracted, usually concealed in the calyx but sometimes protruding sideways 11
11. Flowers 7-10 (15), peduncle longer than petiole (up to 2x as long) *M. tornata*
11. Flowers 5 or less, peduncle, shorter or longer than petiole 12
12. Peduncle shorter or longer than petiole, 3-5 flowers *M. littoralis* cv. Harbinger*
12. Peduncle shorter than petiole, 1-2 (5) flowers 13
13. Calyx lobes densely hairy, calyx teeth reaching $\frac{3}{4}$ or more the standard petal length, young pods pubescent *M. truncatula**
13. Calyx lobes moderately hairy, teeth at most $\frac{3}{4}$ length of standard petal, young pods sparsely hairy *M. littoralis**

* Mature fruits may be necessary to distinguish these species.

Species descriptions

Medicago arabica (L.) Huds., Fl. Angl.
288 (1762)

Synonymy: *M. maculata* Willd., Sp. Pl. 3: 1412 (1802).

Australian representation: The variability observed in Australia covers almost the whole species except that plants with spineless burrs, or without a purple leaf mark have not been reported.

Description: Stems, peduncles and petioles sparsely or moderately hairy, mainly *articulated hairs* on the stems and petioles, both simple and articulated hairs on the peduncles. Central leaflets usually wider than long, 10-25 mm long \times 10-28 mm wide, cuneate or obcordate, upper leaves more obovate, apex retuse or emarginate, upper surface glabrous *with an upper-central purple mark* ranging from a small dot to a large inverted V, or a wide basal shield occupying the basal $\frac{2}{3}$ of the leaf, no other purple flecks but sometimes small white flecks (the purple blotch may fade in herbarium specimens), lower surface sparsely or densely hairy,

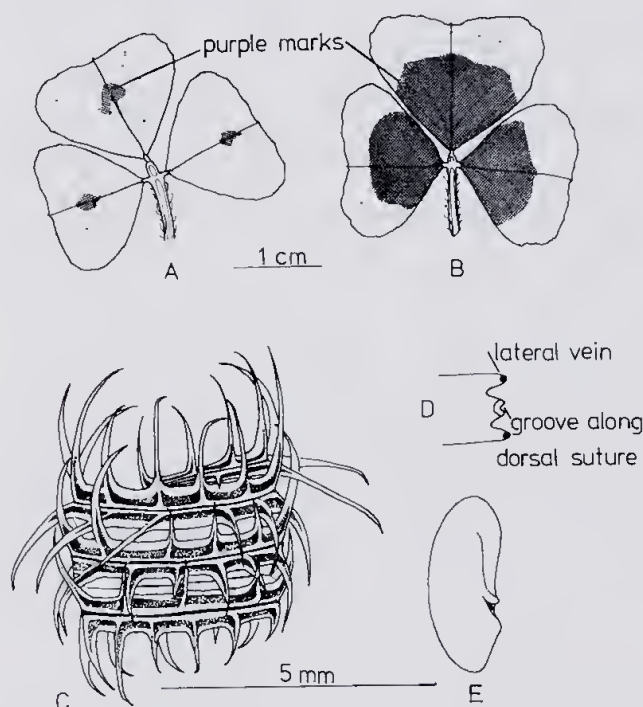


Figure 4.—*Medicago arabica*. A and B: leaf types. C: burr. D: diagrammatic T.S. of coil edge showing relative position of veins and grooves. E: seed.

simple hairs on the lamina and a few articulated ones on the mid rib. Seedling leaves sometimes digitate, older leaves clearly pinnate. In more luxuriant specimens the number of leaflets may occasionally be 4 or 5. Petioles may be very long (up to 15 cm). Stipules with small sharp teeth, sparse or dense articulated hairs on lower side only. Peduncles much shorter than the subtending petioles (peduncles may be only $\frac{1}{3}$ or $\frac{1}{5}$ of the petiole) with a slender awn \pm 3 mm long with simple and articulated hairs. Flowers 2-4(5) per raceme, calyx with moderately dense simple hairs, teeth equal to tube; standard 4-5 mm long, keel \pm 1 mm longer than

the wings. Developing pod contracted and protruding sideways from the calyx, coiling anticlockwise. Mature fruits 1-4 per raceme, barrel-shaped, top coils markedly concave, basal coils less so, 4-6 soft coils not firmly appressed, (4) 5-7 mm diameter, 5-7 mm high, with soft intermeshed spines up to 4 mm long which have a clear basal groove, inserted at 90-120° to the coil surface, tips straight or slightly hooked, pod surface glabrous. Few radial veins, veins distinct in the centre but anastomosed into a fine net towards the outer edge of the coil, lateral veins in the same plane or protruding slightly beyond the dorsal suture, a deep groove between each lateral vein and the dorsal suture and a shallow one bisecting the dorsal suture. (A coil viewed from the edge has 4 ridges and 3 grooves). Seeds, 5-8, separated by thin membranes, subreniform, yellow to light brown, 2½-3 mm long, $\pm 1\frac{1}{2}$ mm wide, radicle longer than half the length of the cotyledons, extreme tip of radicle may protrude vertically, hilum small. $2n = 16$.

Common name: "Spotted medic" or "spotted burr medic". These names refer to the prominent leaf blotch, and the resemblance of this species to burr medic, *M. polymorpha*.

Cultivars: None.

Distribution: Naturalized but uncommon on fertile soils in the lower south west of Western Australia and around Perth.

Medicago intertexta (L.) Mill., Gard. Dict. ed. 8, No. 4 (1768)

Synonymy: *M. ciliaris* Willd., Sp. Pl. 3:1411 (1802) p.p.

M. ciliaris All., Fl. Pedem. 1:315 (1785).

M. echinus DC., Fl. Fr. 4:546 (1805).

Australian representation: The description is of naturalized material of *M. intertexta* var. *intertexta*. All naturalized material appears to have the basal leaf mark but this is not a varietal characteristic. Black (1957) records *M. ciliaris* Willd. (= *M. intertexta* var. *ciliaris* (L.) Heyn), from South Australia but I have been unable to confirm the occurrence of this variety other than in collections of imported material at agricultural research stations (Hj. Eichler, pers. comm.). Variety *decandollei* is endemic to Sicily and not naturalized in Australia. The validity of Heyn's (1963) taxonomic treatment might be questioned as in crosses between var. *intertexta* and var. *ciliaris* Lesins *et al.* (1968) showed that leaf markings and pod hairs were probably under the control of single genes but hybrid fertility was only 40%. Lesins considers the two taxa to be separate species.

Description: Stems and petioles glabrous, peduncles with sparse simple hairs. Central leaflets 15-20 mm long x 8-15 mm wide, obovate or oblanceolate, apex apiculate, edge serrate almost to base, upper surface glabrous, lower surface sparsely hairy. Upper surface with a purple, basal shield-shaped mark, no other leaf flecks. This mark may fade in older plants and is not always retained in herbarium material. Stipules deeply dentate, sparse hairs on lower side or confined to margin. Peduncle variable length,

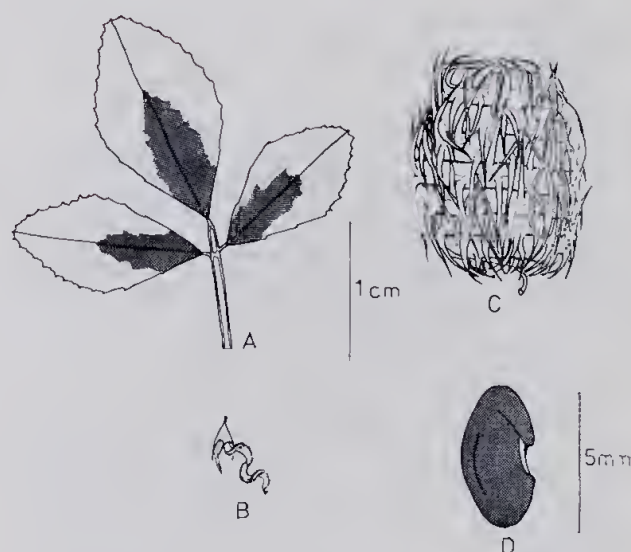


Figure 5.—*Medicago intertexta* var. *intertexta*. A: leaf. B: young developing burr. C: burr. D: seed.

often longer than subtending petiole in flower, equal in fruit, awn from very short to 5 mm, glabrous, often easily detached. Flowers 3-7 calyx with a few hairs at base of teeth, teeth equal to tube or longer. Standard 7-10 mm, keel and wings almost equal or wings longer. Developing pod initially not contracted but protruding sideways from the calyx in a long spiral coiling anticlockwise. Mature fruits 1-2 per raceme, spherical to ovoid, 10-14 mm diameter, 11-16 mm high, 8-11 coils loosely appressed, glabrous, with long intermeshed spines up to 6 mm long inserted at 90°-100° to surface of coil, tips not hooked, clear basal groove. No lateral veins, radial veins anastomosed into a net and one vein running from this net into the base of each spine. The dorsal suture has a central groove. Seeds 5-11, no partitions between the seeds, subreniform black, 3-5½ mm long x 2-3 mm broad, radicle less than ½ the length of the cotyledons, tip clear but not protruding, hilum and strophiole region brown. $2n = 16$.

Common name: "Calvary medic"—relating to the old myth that the blood red leaf marks resulted from blood from the crucifixion; hedgehog medic—relating to the very spiny burrs.

Cultivars: None.

Distribution: Only two specimens have been collected from Western Australia: from Busselton (1928) and Brunswick (1916). As there are no recent collections, it is doubtful if the species has persisted.

Medicago laciniata (L.) Mill., Gard. Dict. ed. 8, No. 5 (1768)

Australian representation: Varieties *laciniata* and *brachyacantha* Boiss. both occur in Australia.

Description: Stems, petioles and peduncles with sparse simple hairs, central leaflets 8-11 mm long x 4-6 mm wide, oblanceolate, apex truncate, retuse and apiculate or tridentate, leaf margins serrate or irregularly laciniate, upper surface glabrous, lower surface with sparse or

dense simple hairs. Leaves may show purple and white flecking. Stipules deeply incised or laciniate, simple hairs on lower side only. Peduncle longer or shorter than subtending petiole, extended into an awn 1-3 mm long glabrous or with a few hairs. Flowers 1-2(3), calyx sparse to moderately hairy, teeth shorter than the tube. Standard $4\frac{1}{2}$ -6 mm long, keel slightly longer than the wings. Developing pod contracted but protruding sideways from the calyx coiling anticlockwise. Mature fruits 1(2) per raceme, olive-shaped, globular or cylindrical, 5-6 mm diameter, 5-7 mm high, burrs soft at maturity, 5-8 coils not strongly appressed, spines $2-4\frac{1}{2}$ mm long,* inserted at 90° - 180° to surface of coils, tips hooked, distinct basal groove, pod surface glabrous or with a few simple hairs.

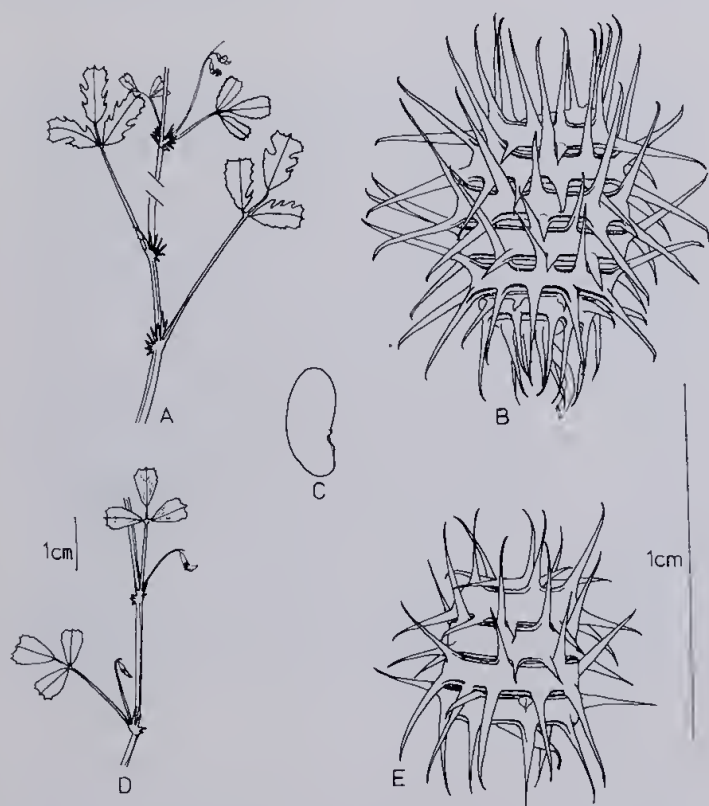


Figure 6.—*Medicago laciniata*. A-C: var. *laciniata*. A: vegetative morphology. B: burr. C: seed. D-E: var. *brachyacantha*. D: vegetative morphology. E: burr.

Radial veins S-shaped and not anastomosed until they enter lateral veins which are separated from the strongly developed dorsal suture by a deep groove. Dorsal suture region glabrous and in fresh material often glaucous. Seeds (7)9-12(14) not separated by partitions, oval-slightly reniform yellow to brownish yellow, 2-3 mm long, 1-1.5 mm wide, radicle longer than half the cotyledons, radicle tip clear but very rarely curled out, hilum a small hollow. $2n = 16$.

* Considerable variation in spine development may be observed in burrs on the same branch (e.g., specimens from Parkeston railway sheds, PERTH.). It is not certain that this is natural variation, as Mr. A. C. Linto of the W.A. Agriculture Department has suggested that it may be due to treatment of railway reserves with hormonal weedcides.

Varieties:

1. Burrs with a 5-8 coils olive-shaped or globular, peduncle longer than petiole, stipules laciniate, at least some leaves laciniate—var. *laciniata*
1. Burrs with 3-4½ coils cylindrical, peduncle shorter than petiole, stipules incised, leaves dentate—var. *brachyacantha* Boiss.

Common name: "Cut-leaf medic" which refers to the dissected appearance of some of the leaves of var. *laciniata*. The name is also loosely applied to var. *brachyacantha* which does not have laciniate leaves.

Cultivars: None.

Distribution: Of limited occurrence in the lower rainfall areas usually in the same region as *M. minima*; north-eastern fringe of the cereal-growing areas of W.A. and east of Kalgoorlie. Variety *brachyacantha* appears the less common. In Israel var. *brachyacantha* occurs in more extreme desert habitats than var. *laciniata* (Friedman in Heyn 1971).

***Medicago littoralis* Rohde* ex Lois-Delong., Not. Fl. France: 118 (1810)**

Australian representation: Naturalised *M. littoralis* is rare in Western Australia and only the var. *littoralis* has been recorded. *M. littoralis* cv. Harbinger is described separately as it is unlike the typical naturalised *M. littoralis*.

Description: Stems, petioles and pedicels with moderate-dense simple hairs. Central leaflets 7-14 mm long x 7-11 mm broad, cuneate or obovate, apex truncate retuse or obtuse, apiculate, margin serrate along upper ½, upper surface sparse-densely hairy, lower surface densely hairy, purple flecks on upper side, sometimes concentrated along the mid rib. Stipules deeply incised with sparse hairs on lower side. Peduncle usually shorter than subtending petiole in flower and fruit, with a hairy awn up to 5 mm long. Flowers 1-3, calyx moderately hairy, teeth longer than tube (atypical for *littoralis*). Standard 5-7 mm long, keel longer than the wings. Developing pod contracted concealed in calyx or protruding sideways, coiling anticlockwise. Mature fruit 1-2 per raceme, cylindrical, 4-5 coils strongly appressed, hard at maturity, 5-6 mm diameter, 5-7 mm high, few hairs on young pods, glabrous at maturity. Venation difficult to see, about 10 radial veins on the coil surface, anastomosing and entering a lateral vein separated from the dorsal suture but in the same plane on the edge of the coil, region between dorsal suture and lateral vein flat, spines long (up to 4 mm) hooked at tips, no basal groove, inserted at 130° in middle to 90° on end coils. Seeds 6-8(9), separated by partitions, subreniform or reniform, yellowish, $2\frac{1}{2}$ -4 mm long x $1\frac{1}{2}$ -2 mm wide, radicle less or just equal to half the length of the cotyledons, tip clear, rarely slightly protruding, hilum, obscure. $2n = 16$.

* The description of this species was sent to Loiseleur-Deslongchamps by MM. Rohde, Bertoloni, Suffren and Requien. In later works the species name is frequently spelled incorrectly *littoralis* and the authority given as Rhode.

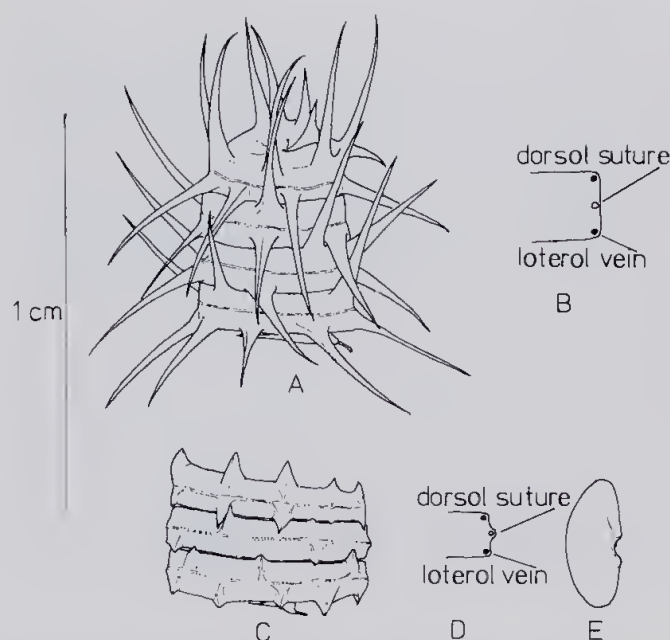


Figure 7.—*Medicago littoralis*. A-B: var. *littoralis*. A: burr. B: diagrammatic T.S. of coil edge. C-E: cv. Harbinger. C: burr. D: diagrammatic T.S. of coil edge. E: seed.

Common name: 'Strand medic' selected by the Victorian Herbage Liaison Committee to describe the coastal distribution of this species in its native Mediterranean habitat.

Cultivars: cv. Harbinger.

Distribution: There are two records of *M. littoralis*. One is a roadside population which has been known for several years, 10 km south of Geraldton on Mr. E. K. Doncon's property. It was collected by Mr. G. L. Throssell in 1958 and incorporated into the W.A. University *Medicago* collection as No. 2500. This accession has been used in crosses between *M. littoralis* and *M. truncatula*, and *M. tornata* (Simon 1965; Simon and Millington 1965).

The second record is a PERTH specimen "Merredin test rows—seed from J. Suiter, Moorine Rock". In view of the preference of *M. littoralis* for coastal habitats the Moorine Rock specimen seems unlikely to be from a naturalized population.

Cultivar Harbinger. 'Harbinger' has been registered as a cultivar of *M. littoralis*. *M. littoralis* is known to hybridize with both *M. truncatula* and *M. tornata* in the field (Heyn 1963) and artificially (Simon 1965; Simon and Millington 1965), and cv. Harbinger appears to have had a hybrid origin. Vegetative features such as the lengths of the branches, and shape of leaflets in cv. Harbinger relate to *M. truncatula* or *M. tornata* rather than *M. littoralis* while the size of the leaflets, the number of flowers, and perhaps the peduncle: petiole ratio indicate some introgression to *M. tornata*. The position of the lateral veins on the surface rather than the extreme edge of the coils, the presence of indentations between spine bases and the insertion of the spines at 90° rather than 130° are *M. truncatula* characteristics. The only features of *M. littoralis* are the calyx teeth which are

broad at the base and about equal to the tube in length, and the pollen which is spindle-cylinder shaped when dry and shows 3 pores when stained, as is typical for *M. littoralis* (Lesins and Lesins 1963). *M. truncatula* pollen is triangular to pyramidal or bisphenoid when dry and shows 4, (rarely 5 or 6) pores when stained. I have observed that *M. tornata*, a species not included in the Lesins' survey, has the same pollen morphology as *M. littoralis*.

The origin of cv. Harbinger is confused and it is suggested that it may have originated from Iran in 1940 (Barnard 1972). However, Heyn (1963) states that *M. truncatula*, *M. littoralis* and *M. tornata* do not occur in Iran. If the argument for a hybrid origin is accepted, then the source locality for cv. Harbinger must be a region where two or all three of the species grow and may hybridize.

Description: as for *M. littoralis* with the following points of difference:

Central leaflets (11) 16-19 mm long x 8-11 broad, cuneate only in the rosette stage, obovate or oblanceolate, apex obtuse and apiculate, margin serrate in upper half, rare purple flecks on the upper side. Peduncle equal or longer than subtending petiole in flower, equal or shorter in fruit. Flowers 3-5, calyx teeth equal or shorter than tube. Mature fruits (2) 4-5 per raceme, 3-4 coils, 4-5 mm diameter x 2½-3½ mm high. Lateral veins on the surface of the coil rather than the extreme edge, separated from the dorsal suture by a groove in young and mature pods, except in the most fleshy thickened burrs. Spines short and straight or tubercles, variable in length on the same pod or between pods on the same plant. Seeds 3-4 (5), 3-3½ mm long x 1¼-1½ broad.

Distribution: The cultivar does best on deep yellow sands in the northern cereal areas and is occasionally naturalised along roadsides in the Geraldton district. It is also grown near Salmon Gums.

Medicago lupulina L., Sp. Pl. 2:779 (1753)

Australian representation: The naturalized Western Australian material behaves as an annual (Quinlivan (1965) but Barnard (1969) reports that in other states plants may be biennial or perennial. The species is commonly included in *Medicago*, and crosses between *M. sativa* and *M. lupulina* are possible when *M. sativa* is used as the female parent (Southworth 1914; Schröck 1943). *M. lupulina* has non-articulated cotyledons, a generic characteristic of *Medicago*, but it is very like *Melilotus* in its vegetative parts, inflorescence and nutlet-like pod. Further, some forms lack the typical *Medicago* floral tripping mechanism (Heyn 1963) and it has been mentioned above that the thickening of the anther sheath and swelling of the bases of alternate anthers may be reduced or absent. Thus some forms of *lupulina* do not possess all the characteristics necessary for inclusion in *Medicago* and Simon (1969) as shown serological differences between *M. lupulina* and *M. secundiflora* (Section *Lupularia*) and the remaining species of *Medicago*.

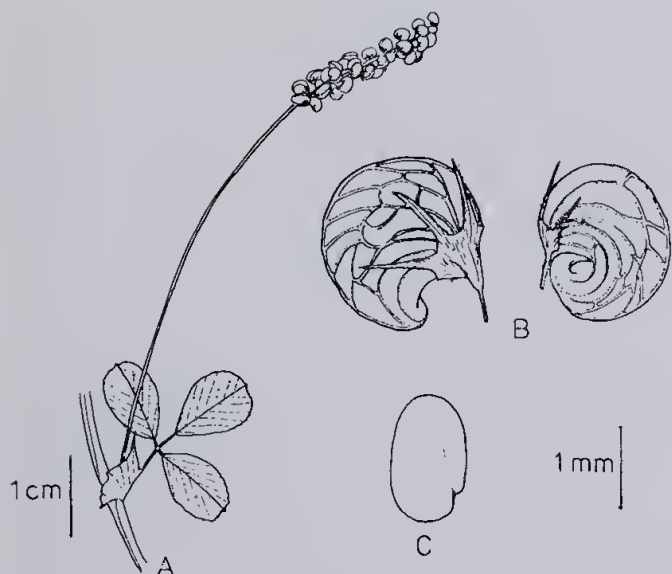


Figure 8.—*Medicago lupulina*. A: leaves and fruits. B: fruits (hairs on leaves and fruits not shown). C: seed.

Description: Stems, petioles and peduncles densely covered with simple hairs. Central leaflets from leaves in rosette $4\frac{1}{2}$ - $6\frac{1}{2}$ mm long x $4\frac{1}{2}$ -7 mm broad, orbicular, cuneate or obovate, sometimes appearing digitate, with petioles up to 7 cm long; leaves on branches 11-15 mm long x 6-10 mm broad, obovate-oval, apex retuse or apiculate, upper half of margin serrate, clearly pinnate, and petioles rarely more than 1 cm long upper surface virtually glabrous to densely hairy, lower surface always densely hairy. No leaf flecks or marks. Stipules entire or dentate, upper surface usually glabrous (rarely a few hairs), lower surface densely hairy. Peduncles longer than subtending petioles in flower, elongating in fruit to reach 3-5 times the petiole, awn lacking or small ($1-1\frac{1}{2}$ mm long and difficult to see), floral bracts \pm equal to pedicel. **Flowers** (10) 20-50 in dense oblong heads 10 mm or more long. Calyx moderately hairy the 3 anterior teeth slightly longer, and the 2 posterior teeth shorter than the tube. **Standard** $2-2\frac{1}{2}$ mm long, sometimes only just longer than the calyx teeth, wings slightly longer than the keel. **Pod** a single-seeded nut with only the distal end coiled. Mature fruits 10-40 per raceme, reniform with convex sides, or discoid, $2-3\frac{1}{2}$ mm long x 1-2 mm wide, spineless, glabrous or hairy with appressed or erect, simple, or simple and glandular hairs. Pod often blackening when ripe, prominent radial veins in almost concentric semicircles, anastomosing and running into the dorsal suture. Single seeds, round or oval, yellow or yellow-brown, $1\frac{1}{4}$ - $2\frac{1}{2}$ mm long x $\frac{3}{4}$ - $1\frac{3}{4}$ mm wide, radicle longer than half the length of the cotyledons, tip distinct and rarely slightly protruding. $2n = 16, 32$: it is not known whether both types occur in Australia. **Common names:** 'Black medic' which relates to the black fruits of the species.

Cultivars: None, but it is interesting to note that this species was the first medic offered for sale in Western Australia in colonial times (Quinlivan *et al.* 1974).

Distribution: Rare in Western Australia. Herbarium specimens from Elleker (W. of Albany), Denmark, Yarloop and Nungarin do not distinguish between plants deliberately cultivated and naturalized occurrences. It is a late maturing species and in other Australian states is naturalized in the cooler districts to specimens from the first 3 localities are possibly from naturalized stands but it is unlikely that the species is naturalised at Nungarin. It is known to have been established around Deeside at Lake Muir but it does not appear to have persisted (Quinlivan, pers. comm.).

Medicago minima (L.) Bart., Cat. Plant. Siena: 61 (1776)

Synonymy: *M. minima* (L.) Grufbg., Fl. Angl.: 21 (1754).

Australian representation: Most of the range of variability for the species is seen in Australian material. However, the maximum number of flowers appears to be 5, (in var. *brevispina*), while in Mediterranean material up to 8 flowers have been recorded.

Description: Stems, petioles and peduncles densely covered with simple hairs, or, especially in some var. *brevispina*, simple and glandular hairs. Central leaflets 5-14 mm long, $3\frac{1}{2}$ -7 mm broad, leaflets from the rosette may be orbicular, cuneate or obovate, on branches they are obovate or oblanceolate, apex retuse, mucronate or tridentate, upper $\frac{1}{3}$ of margin serrate, upper and lower surfaces densely hairy with simple, or simple and glandular hairs. Upper surface of leaf lamina may be without flecks or marks or have a dense line of purple flecks along the mid

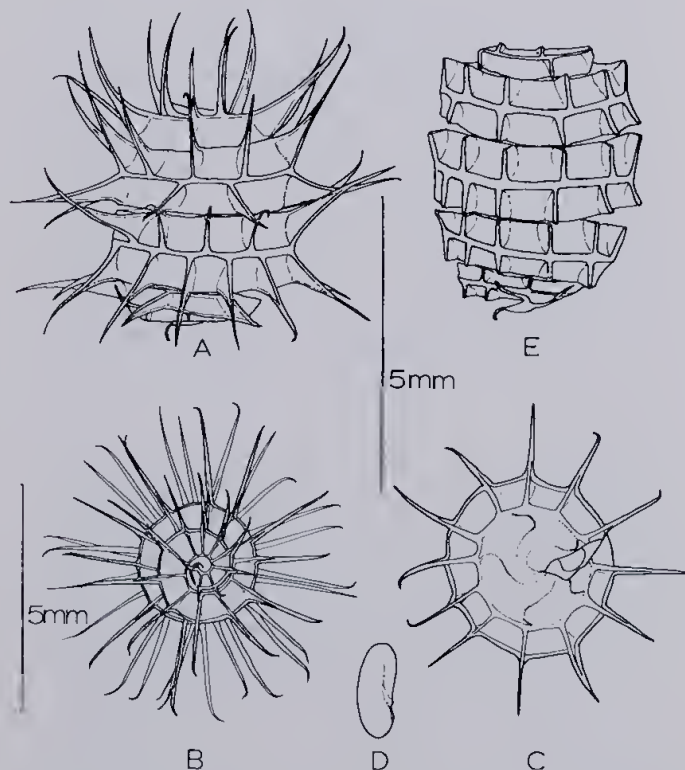


Figure 9.—*Medicago minima*. A-D: var. *minima*. A and B: burr types. C: venation on coil surface. D: seed. E: var. *brevispina* burr. (hairs on burrs not shown).

rib. In the rosette, petioles may reach $4\frac{1}{2}$ cm but on the branches they are usually only 1 cm long. *Stipules entire or with small teeth*, hairy on both sides. The pubescence on the vegetative parts may give the plant a *greyish tomentose* appearance. Peduncles shorter or longer than the subtending petiole, extended into a short hairy awn (1-2 mm long) which may be difficult to see. Flowers 1-2 (-5 in var. *brevispina*), calyx densely hairy teeth longer than the tube the 3 anterior teeth being slightly longer than the 2 posterior ones. Standard $3\frac{1}{2}$ -5 mm long, wings and keel of equal length or keel slightly longer. Developing pod contracted, protruding sideways from the calyx, coiling anticlockwise. Mature fruits 1-2 (-5 in var. *brevispina*) per raceme, discoid, olive-shaped or barrel-shaped. $3\frac{1}{2}$ -5 soft thin walled coils not firmly adpressed, 3-5 mm diameter, $2\frac{1}{2}$ -5 mm high, glabrous or with simple, or simple and glandular hairs, spineless, tuberculate or with long hooked spines (up to $3\frac{1}{2}$ mm), inserted at 180° to coil surface in centre coils, and about 120° in apical coils, long clear basal groove. Radial veins few (6-8) strongly bent to S-shaped, not anastomosing, joining a marked *lateral vein which is separated from the dorsal suture by a slightly concave margin about $\frac{1}{3}$ the radius of the coil*, across which run only the veins to the spines. Dorsal suture marked but not as wide as in *M. laciniata* or *M. praecox*. Seeds (3) 4-6 (7) per burr, *not separated by membranes**, oval-subreniform, yellow or yellow-brown $1\frac{1}{2}$ - $2\frac{1}{4}$ mm long, $\frac{3}{4}$ - $1\frac{1}{4}$ mm wide, radicle slightly longer than half the cotyledons, tip may protrude slightly, hilum obscure. $2n = 16$.

Varieties (from Heyn, 1963):

1. Burr discoid or ovate, spines hooked, longer than $\frac{1}{2}$ the radius of the coils—var. *minima*
1. Burr olive—or barrel-shaped, spines lacking, tubercles or short straight spines less than $\frac{1}{2}$ the coil radius—var. *brevispina* Benth.

The drawing of var. *brevispina* (Fig. 9E) is of a line similar to that sometimes referred to as *M. sesilis* Peyr. Burrs with no trace of spines and the coil edges completely smooth are also known.

Common name: 'Woolly burr medic', derived from the superficial resemblance of the burr to burr medic (*M. polymorpha*), and the woolly pubescence of the plants. "Goldfields medic" due to its distribution in Western Australia, or rarely and incorrectly, "Kalgoorlie Clover". 'Little medic' is the common name in Victoria (Willis 1972).

Cultivars: None.

Distribution: Widespread but of isolated occurrence in drier parts of the wheat belt extending into semi-arid sheep country. As far N. as Port Gregory, E. to Norseman and S. to Ravensthorpe, most common in the Merredin and Kalgoorlie districts. The spineless var. *brevispina* has been collected from near Merredin (Quinlivan and Francis, pers. comm.). Spread of the species has sometimes been assisted by farmers in the eastern wheatbelt by raking up burrs and distributing them on their properties.

* Heyn (1963) states that there are thin interseminal membranes but these were not seen in Australian material.

Medicago orbicularis (L.) Bart., Cat. Plant.
Siena : 61 (1776)

Australian representation: The Australian material appears to be from the types with large burr sizes. The species is particularly variable and many attempts have been made to create intraspecific taxa. Heyn (1963) does not recognize any varieties as she considers that all characters used in previous subdivisions were not sufficiently discontinuous.

Description: Stems, petioles and peduncles with sparse to moderately dense simple hairs, or simple and glandular hairs. Central leaflets 11-17 mm long \times 9-13 mm broad, cuneate or obovate, apex retuse or apiculate, marginal serration extending almost to base, upper surface glabrous, lower surface sparsely hairy. Stipules deeply incised or lacinate, glabrous or a few hairs on the lower side, mainly along the margins. Peduncle usually shorter than the subtending petiole in flower, sometimes equal in fruit, produced to a long awn (up to $6\frac{1}{2}$ mm) with a few hairs. Flowers 1-2(5), calyx moderately hairy with teeth longer than the tube, standard 4-6 mm long, keel \pm 1 mm longer than the wings, developing pod initially not contracted but protruding sideways from the calyx as a long spiral, coiling anticlockwise. Mature fruits 1(2) per raceme, pod shape (W.A. material) lenticular widest coil in the middle 13-17 mm wide, $3\frac{1}{2}$ -7 high, spineless, glabrous. Simple or simple and glandular hairs (often early deciduous), 4-7 soft coils not firmly adpressed, *with a wide thin border often undulating*. Straw coloured or blackening to different degrees. *No lateral veins*, radial veins anastomosed into a net and running to dorsal suture, sometimes thick and raised towards the dorsal suture coil margin. Seeds (10) 15-20(26) separated by short partitions

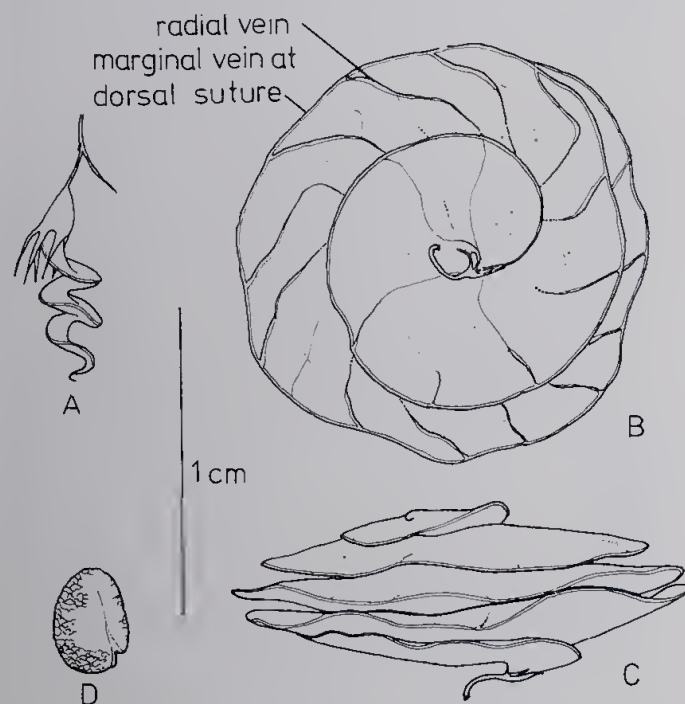


Figure 10.—*Medicago orbicularis*. A: developing fruit. B: ventral surface and C: side view of fruit (hairs not shown). D: seed.

which do not extend out to the edge of the coil, orientated so that the *radicle is vertical to the axis* (rather than tangential as in other Australian species), *surface rough or minutely tuberculate* (all other Australian species are smooth), yellowish-brown triangular in shape, *the radicle being almost as long as the cotyledons*, tip clear but not protruding, 3-3½ mm long x 1½-3 mm broad, hilum small. $2n = 16$.

Common name: "Button Medic"—derived from the pod shape.

Cultivars: Nene.

Distribution: A single herbarium specimen from Southern Cross, collected in 1925. It seems unlikely that the species would naturalise in this area as records from other states indicate that it requires a long growing season and is late maturing (Barnard 1969).

Medicago polymorpha L., Sp. Pl. 2:779 (1753)

Synonymy: *M. hispida* Gaertn., De Fruct. 2:349 (1791).

M. lappacea Desr., in Lam. Encycl. Method. 3:637 (1772) p.p.

M. apiculata Willd., Sp. Pl. 3:1414 (1802) p.p.

M. denticulata Willd., Sp. Pl. 3:1414 (1802) p.p.

M. terebellum Willd., Sp. Pl. 3:1416 (1802) p.p.

M. reticulata Benth., Cat. Pyr. 101 (1826) p.p.

M. confinis Koch., Syn. Fl. Germ. ed I. 164 (1837) p.p.

Australian representation: The species is a widespread weed and occasional pasture component and examples are found of all the three varieties described by Heyn (1963): var. *polymorpha*, var. *vulgaris* (Benth.) Shin., var. *brevispina* (Benth.) Heyn. The separation of these varieties is unsatisfactory as there is an abundance of material intermediate between all varieties.

Description: Stems, petioles and peduncles virtually glabrous or sparse hairs on young petioles and peduncles. Central leaflets 8-20 (27) mm long x 7-15 (19) mm wide, cuneate to obovate, apex obtuse or retuse, apex apiculate, margin almost entire or with upper ½ serrate, upper surface glabrous, lower surface glabrous or with sparse hairs. Leaves sometimes with purple and/or white flecks, and/or a basal purple mark which may be either a solid or an empty inverted V. Stipules deeply incised to lacinate, glabrous or a few hairs concentrated along the margin. Peduncle usually shorter, or sometimes longer, than subtending petiole, awn lacking or up to 3 mm long. Flowers (1)2-7 (8), calyx with few hairs, teeth longer than the tube. Standard 3-5 mm long, *wings longer than keel*. Developing pod initially contracted and protruding sideways from the calyx, coiling anticlockwise. Mature fruits 1-5 per raceme, discoid, cylindrical, or truncated cone, 4½-8½ mm wide x 2-10 mm high, without spines or with short or long spines (up to 3½ mm), the longer ones usually hooked and with a short groove at the base, inserted at 180° to pod surface on middle coils sometimes 90° on apical coils, 1½-6½ coils, soft or hard at maturity, not strongly appressed, surface glabrous or sparsely hairy. *Many (15-20 per coil) radial veins strongly curved, anastomosing into a net and joining a lateral vein which is separated from the wide*

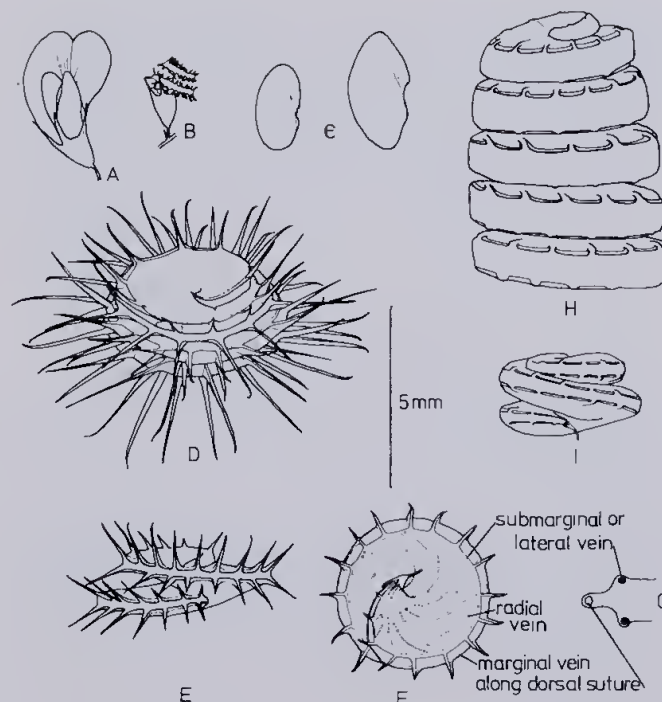


Figure 11.—*Medicago polymorpha*. A: flower. B: developing burr. C: seeds. D: var. *polymorpha* burr. E: var. *vulgaris* burr. F: venation on ventral coil. G: diagrammatic T.S. of coil edge. H and I: var. *brevispina* burr types.

dorsal suture by a narrow groove. Seeds (3) 4-8 (11) per burr, separated by partitions, oval to subreniform, yellow-yellow brown, 2½-4 mm long x 1½-2½ mm broad, radicle equal or less than half the length of the cotyledons, tip not at all protruding. $2n = 14$.

Varieties (from Heyn 1963 and 1970):

var. *polymorpha*: Spines of fruit thick and hardened, coils 4-6, hardening at maturity, diameter of broadest coil 5-8 (10) mm (coils sometimes 3½, the diameter exceeding 6 mm); inflorescence usually few flowered, (1) 2-5 flowers).
var. *vulgaris* (Benth.) Shin. in Rhodora 58:310 (1956) emend. Heyn, Scripta Hierosolymitana 12:75 (1963). Spines of fruit slender, coils 1½-3½ usually soft, even at maturity, diameter of broadest coil (2) 3-5 (6) mm, inflorescence usually many flowered (5-10 flowers).

var. *brevispina* (Benth.) Heyn, Scripta Hierosolymitana 12:77 (1963). Spines lacking, margin of coils smooth or tubercled, coils (2)3-5 often hardening at maturity, diameter of broadest coil (2½) 3-4 (5½) mm, inflorescence (1) 2-10 flowers.

In Western Australian material there appears to be spineless forms of var. *vulgaris* with up to 5 fruits per raceme and small burrs (4-6 mm diameter x 2-3 mm high with 2-2½ coils), and spineless forms of var. *polymorpha* which have 1-2 fruits per raceme and larger burrs (4-6 mm diameter x 4-6 mm wide with 3½-4 (5) coils). All the spineless material is classified as var. *brevispina*.

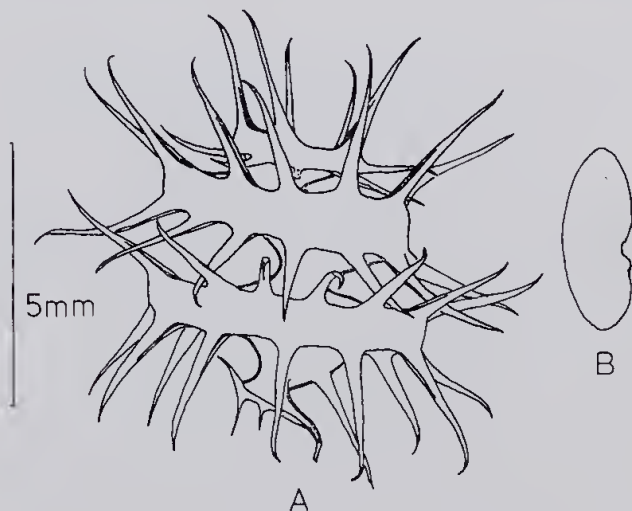
Common names: "Burr medic" which relates to the spiny pods, or, more rarely, "toothed medic", which is derived from one of the synonyms, *M. denticulata*, and refers to the very small teeth usual on the leaf margins.

Distribution: The spiny varieties of the species are established in most of the agricultural and pastoral areas, extend into the Goldfields, and may be found as adventitious weeds in suitable wet places such as wells and tanks, along roads and railway lines as far north as Carnarvon and east to Forrest. The spineless form is rare but is distributed throughout the most of the range of the spiny varieties.

Medicago praecox DC., Adnot. Cat. Hort.
Monsp. :123 (1813)

Australian representation: The description for Australian material encompasses the whole species. There are no varieties described for this species and it shows less variation than some other *Medicago* species.

Description: Stems, petioles and peduncles with sparse to moderately dense simple hairs. Central leaflets 5.5-9 mm long, 5-9 mm broad, obcordate, or obovate, apex apiculate, upper 1/3 of margin serrate, upper surface glabrous, lower surface densely hairy, no purple flecks or leaf marks.



Figures 12.—*Medicago praecox*. A: burr. B: seed.

Stipules deeply incised, with a few simple hairs on the lower side only. Peduncles much shorter than the subtending petiole in both flower and fruit, no awn, or rarely a very short one (± 0.5 mm). Flowers 1-2, calyx with moderately dense simple hairs, teeth \pm equal to tube but front 3 teeth slightly longer than back 2. Standard 2-3 mm, keel ± 1 mm longer than wings. Developing pod contracted and protruding sideways from the calyx, coiling anticlockwise. Mature fruits 1 (2) per raceme, coils *not appressed*, shape (without the spines) a cylinder or truncated cone, 4-5 mm diameter, 4-5½ mm high, spines 2-3 mm long, hooked at tips, strongly grooved at the base, inserted at 90°-120° to coil surface, frequently in opposite pairs from the wide dorsal suture, coil surface with sparse hairs, suture region glabrescent. Radial veins 8-12 per coil, strongly curved, anastomosing, entering a distinct lateral vein which is separated from the wide dorsal suture by a *narrow deep groove which is visible from the coil surface rather than from the side of burr*. Seeds (3)4-6,

separated by partitions, oval to subreniform, yellowish, 2-3 mm long \times 1-1½ mm broad, radicle slightly less than half the length of the cotyledons, with tip closely appressed, hilum obscure. $2n = 16$.

Common name: "Small leaf burr medic" as this species is sometimes mistaken for a small-leaved form of burr medic (*M. polymorpha*).

Cultivars: None.

Distribution: The species was previously thought to be absent from Western Australia, but I have found it at 3 widespread localities so it is unlikely to be a recent introduction. (On red soils N. of Mingenew, 20 km N. of Merredin, and E. of Gnowangerup.) Heyn (1963) notes that it is rare, even in the Mediterranean.

Medicago rugosa Desr., in Lam. Encycl.
Method. 3:632 (1792)

Australian representation: The only representative of this species in Australia is the cultivar Paragosa, so this description covers only the variability observed in the cultivar.

Description: Stems, petioles and peduncles densely covered with simple and glandular hairs. Central leaflets 10-23 mm long \times 7-15 mm broad, obovate or oblanceolate, apex obtuse or slightly retuse, upper half of leaf margin serrate, upper surface with rare purple flecks or none, glabrous, lower surface with dense glandular and simple hairs, stipules with small sharp teeth, dense glandular and simple hairs on lower side, very rare glandular hairs on upper side. Peduncle shorter than the petiole of the subtending leaf, sometimes becoming equal when fruiting, peduncle with a hairy awn 4-5 mm long. **Flowers** (1) 3-5 *nearly all inserted on the same side of the peduncle*. Calyx with dense glandular and simple hairs, teeth shorter or equal to the tube. Standard 3-4 mm long, keel slightly longer than the wings. Developing pod contracted but protruding sideways from the calyx, anticlockwise coiling. Mature fruits 1-3 per raceme, 3½-5 concave coils, strongly appressed, 6-9 mm diameter, 3-4½ mm high, spinless, *pod disc- or lozenge-shaped, surface with glandular and simple hairs which may rub off exposed parts of dry burrs*. *No lateral veins*, very marked radial veins arising in opposite or alternate pairs from the thick dorsal suture, no anastomosis in the outer ½ of the pod diameter. Seeds 1-2 (rarely more), *not separated by partitions*, strongly

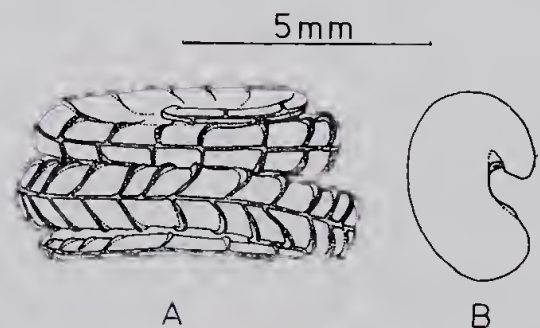


Figure 13.—*Medicago rugosa* cv. Paragosa. A: burr (hairs not shown). B: seed.

reniform, glossy, bright- to dark- or brownish-yellow, 3-4½ mm long, 2-3 mm broad, radicle less than half the length of the cotyledons with a strongly protruding tip, hilum very small and obscure. $2n = 32$.

Common name: 'Gama medic' given to this species by the South Australian Herbage Plant Liaison Committee, as the accession from which the cultivar was selected, (CPI 7791), was originally collected in Portugal, the homeland of Vasco da Gama the navigator.

Cultivar: One cultivar, cv. Paragosa.

Distribution: The cultivar grows best on heavy alkaline soils, and is rarely grown and not naturalized in Western Australia.

Medicago scutellata (L.) Mill., Gard. Dict.
ed. 8: No. 2 (1768)

Synonymy: *M. scutellata* (L.) All., Fl. Pedem. 1: 315 (1785).

Australian representation: The species appears to have been introduced into Australia at the end of the 19th century and while local strains have developed (Quinlivan 1965), the species is, on the whole, one of the less variable annual species. The description is mainly based on plants sold by seed firms as 'Snail medic'.

Description: Stems, petioles and peduncles densely covered with simple and glandular hairs. Central leaflets 15-22 mm long, 10-15 mm broad, oval, obovate or oblanceolate, apex obtuse only in lowest leaves, mainly acute, upper ⅔ of leaf margin serrate, upper surface with rare purple fleck or none, glabrous, lower surface with dense glandular and simple hairs. Stipules with small sharp teeth, *glandular hairs on upper side*, (cf. Heyn 1963) glandular and simple hairs on lower side. Peduncle shorter than the subtending petiole, with a long (± 5 mm) hairy awn. Flowers 1-2(3) per raceme; calyx with dense simple and glandular hairs, teeth equal to or longer than the tube, standard 6-7 mm long, keel very slightly longer than wings. Developing pod contracted and protruding sideways from the calyx (or sometimes contained in the calyx), anticlockwise coiling. Mature fruits 1-2(3) per raceme, spineless, cup-shaped or olive-shaped, 11-14 mm diameter, 11-16 mm high, 5-7 coils, basal coils enclosing upper ones, dense glandular and simple hairs when young, exposed parts \pm glabrous at maturity. Radial

veins distinct, reticulate, no lateral veins. Seeds 4-6, none in the distal 2-3 coils, separated by very thin partitions, reniform, not glossy, yellow or brownish yellow, 4-6 mm long, 2½-3½ mm broad, radicle less than half the length of the cotyledons, tip projecting, hilum distinct. $2n=32$.

Common name: 'Snail medic', which refers to the pod shape.

Cultivars: None.

Distribution: Rarely cultivated and apparently not naturalised in Western Australia.

Medicago tornata (L.) Mill., Gard. Dict.
ed. 8: No. 3 (1768)

Synonymy: *M. obscura* Retz., emend. Urb., Verh. bot. Ver. Brandenb. 15: 66 (1873).

Australian representation: *M. tornata* does not occur in naturalized populations in Western Australia, the specimen reported by Quinlivan (1965) from Ravensthorpe being an incorrectly identified spineless *M. truncatula*. The cultivar Tornafeld is attributable to *M. tornata* var. *tornata*, and although cv. Murrayland is possibly of hybrid origin, having some *M. littoralis* features, it is best also referred to var. *tornata*. The source material for cv. Murrayland is naturalized at Pooncarie, N.S.W.

Description: Stems, petioles and peduncles with sparse simple hairs. Central leaflets 10-17 mm* long \times 9-16 mm wide, obovate, angular obovate, or oblanceolate, apex obtuse, apiculate, upper 2/3 of leaf margin serrate, upper surface glabrous or sparsely hairy, lower surface sparsely hairy. Leaves may have purple and white flecks, and rarely, a narrow ellipsoidal purple mark on the upper surface. Stipules deeply incised, moderately dense hairy on lower side only. Peduncle markedly longer than petiole of subtending leaf (up to twice as long in flower), awn up to 4 mm long with a few hairs. *Flowers (4)7-10(15) crowded in the inflorescence*, calyx with moderately dense hairs mostly at the base of the teeth, teeth longer than the tube. Standard 5-8 (10) mm long, keel longer than the wings. Developing pod contracted and concealed in the calyx or sometimes protruding sideways coiling anticlockwise (in the Australian cultivars). Mature fruits 4-8 per raceme, discoid, cylindrical or a truncated cone 4-7 mm wide (up to 10 mm wide reported in original description of cv. Tornafeld) \times 2-7 mm high, spineless, glabrous, 2-5 convex coils, appressed only in the centre in cv. Tornafeld, and right to the outer edge in cv. Murrayland. Venation difficult to see at maturity, surface of coil with about 10 radial veins which anastomose into a net, and run into lateral veins separated from the dorsal suture, *no groove between the dorsal suture and lateral veins*, edge of coils smooth. Seeds 3-6 per pod, separated by thick partitions, subreniform to strongly reniform, yellow or yellow-brown, 2½-4 mm long \times 1½-2¾ mm wide, radicle less than half the length of the cotyledons, tip appressed. $2n = 16$.

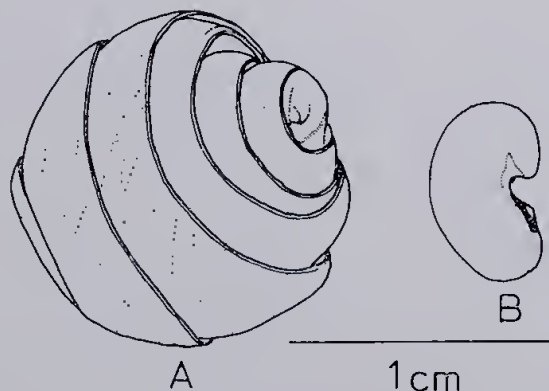


Figure 14.—*Medicago scutellata*. A: burr (hairs not shown). B: seed.

* Leaves up to 30 mm long and 20 mm wide are reported by Millington in the description of the cv. Tornafeld (Barnard 1972) but I have not seen leaves of this size.

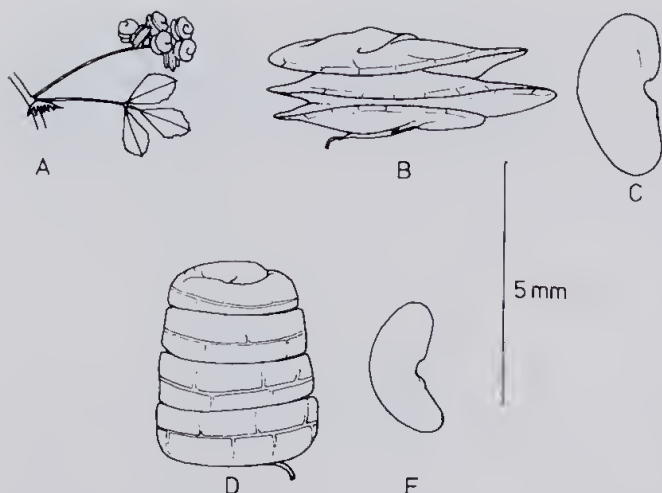


Figure 15.—*Medicago tornata*. A-C: cv. Tornafield. A: leaves (hairs not shown) and burrs. B: burr. C: seed. D and E: burr and seed of cv. Murrayland.

Common name: "Disc medic", chosen by the W.A. Herbage Liaison Committee to describe the fruit of cv. Tornafield which sometimes looks like a series of discs. Barnard has attempted to change this common name to sand medic, arguing that disc medic might be confused with *M. disciformis* DC. and in any case cv. Murrayland has cylindrical rather than disc-shaped burrs.

Cultivars: cv. Tornafield. This was derived from selection among and F₂ of a cross between var. *tornata* and var. *aculeata*, selection being aimed at combining the large burr size and absence of spines of the *tornata* accession with the early flowering of the *aculeata* accession. The number of pod coils in cv. Tornafield is 2-3½ which is at the lower limit of the range observed in naturally occurring var. *tornata* (3-6(8) coils). However in view of the parentage, cv. Tornafield can be included in var. *tornata*.

cv. Murrayland. These plants show some features of *M. tornata*, most importantly the many-flowered inflorescence (4-6 flowers) which has a peduncle much longer than the petiole of the subtending leaf. However the pods of cv. Murrayland are typical of *M. littoralis* var. *inermis* in their cylindrical shape with the coils appressed to the extreme edge, and with the lateral veins at the very edge of the coil in the same plane as the dorsal suture. Heyn (1963) considers that the flower characteristics outweigh the burr morphology and places material such as this in *M. tornata* but notes that introgression with *M. littoralis* has occurred. Similar specimens come from the west Mediterranean and are frequently identified as *M. striata* Bast. The fruits of cv. Murrayland are quite distinctive and cannot be confused with pods of any other naturalised or cultivated species in Australia at present.

Distribution: No naturalized occurrence as yet, but it is likely that the cv. Tornafield introduced in 1969 will soon establish naturalized stands along roadsides in the Geraldton district.

Medicago truncatula Gaertn., emend. Urb., Verh. bot. Ver. Brandenb. 15:67 (1873)

Synonymy: *M. tribuloides* Desr., in Lam., Encycl. Method. 3:635 (1792).

Australian representation: Most of the naturalized material and the cvs. Cyprus, Jemalong and Hannaford are var. *truncatula*, or intermediate between vars. *truncatula* and *longiaculeata* Urb.; cv. Ghor is var. *longiaculeata* Urb., and cv. Borung is var. *tricycla* (Negre) Heyn or intermediate between that variety and var. *truncatula*. The spineless form has not been described as a variety. Heyn (1963, 1970) also notes that intermediate forms occur, and it has been observed that at the beginning of the season a plant may form burrs with thick, straight, strongly appressed spines typical of var. *truncatula*, but burrs formed later may have thinner, curved spines not strongly appressed more like var. *longiaculeata*.

Description: Stems, petioles and peduncles with dense simple hairs. Central leaflets 6-20(25) mm long × 5-14(20) mm wide, cuneate or obovate, apex obtuse, truncate or retuse, apiculate, margin serrate along upper 1/3 surface sparse to densely hairy, lower surface always densely hairy. Upper surface with or without purple flecks, a large central ellipsoidal purple mark, or a small upper central yellow mark faintly bordered with purple. Stipules dentate to deeply dentate, with sparse to dense simple hairs on lower side only. Peduncle usually shorter than petiole in both flower and fruit, a hairy awn up to 5 mm long. Flowers 1-3(4) per raceme, calyx densely hairy, *teeth much longer than the tube* with the 3 anterior teeth sometimes slightly longer than the posterior ones. Standard 4½-7 mm long, keel just longer than the wings. Developing pod contracted and concealed in the calyx or protruding sideways, coiling clockwise or anticlockwise. Mature fruits 1-2 (4) per raceme, a short or long cylinder or a truncated cone, 3-7 coils strongly appressed and thickened at maturity, 4½-8 mm* diameter, 4½-11 mm high*, usually pubescent especially when young, rarely almost glabrous. About 10 radial veins anastomosing and entering a *lateral vein* which is on the surface rather than the edge of the coil, and *which is separated from the dorsal suture by a groove* (particularly marked on young burrs and occasionally obliterated in very thickened mature burrs), spines lacking, short or long (up to 3 mm), straight or curved, base with or without a short groove, sometimes with base very thickened, inserted at 90° to 120°. Seeds (3)4-8(12), separated by thin partitions, subreniform to reniform, yellow to brownish-yellow, 2½-4 mm long* × 1½-2½ mm broad, radicle less than half the total length of the cotyledons, tip appressed. 2n = 16.

Common name: "Barrel medic" which refers to the pod shape.

Cultivars: The main features of the six cultivars are:

cv. Hannaford (previously 'Commercial barrel medic' or 'South Australian barrel medic'):

* The registration description of cv. Cyfield gives the upper limit of pod diameter 12 mm, pod height as 15 mm, and seed length 6 mm. I have not seen material in this size range.

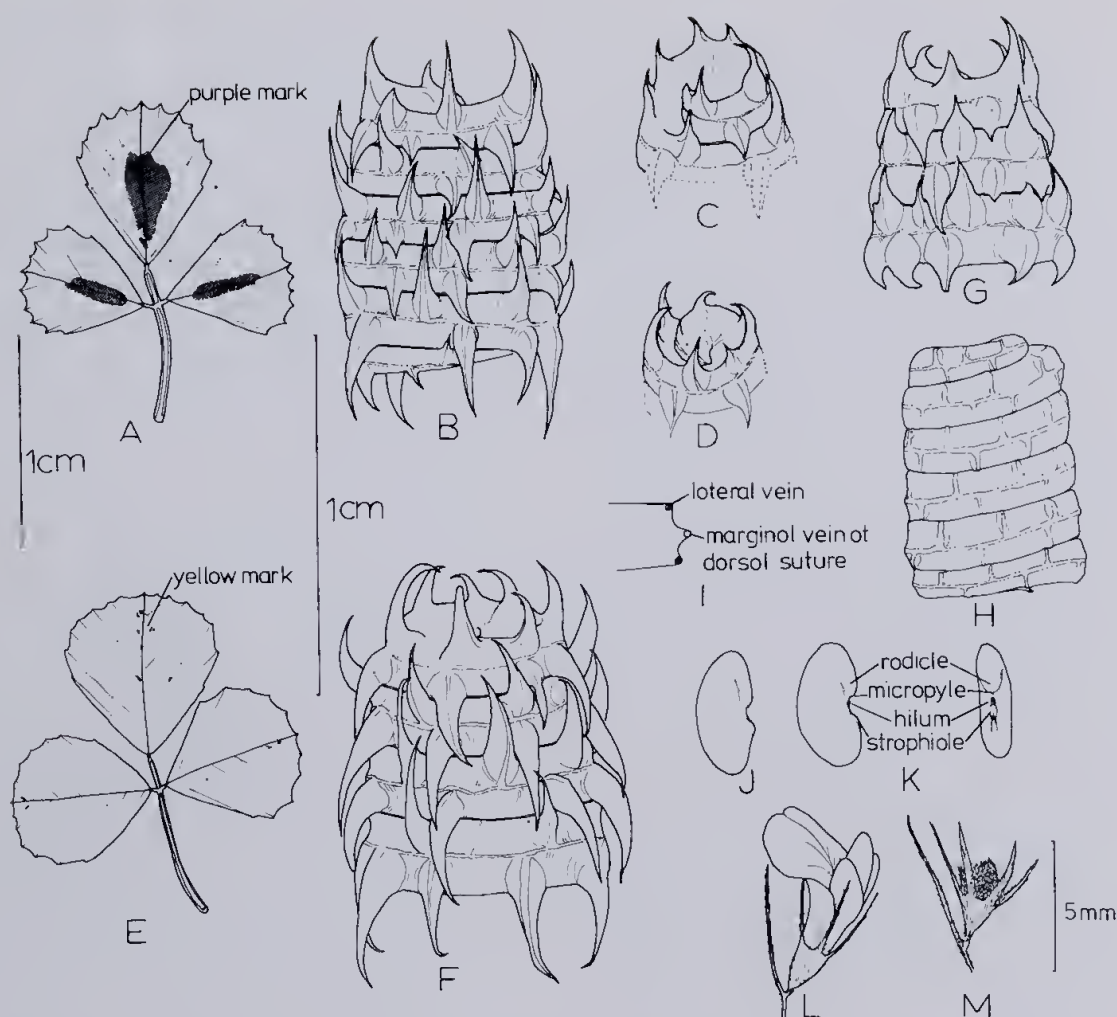


Figure 16.—*Medicago truncatula*. A-C: cv. Jemalong. A: leaf. B: burr. C: apical coils showing anticlockwise coiling. D: cv. Cyprus apical coils showing clockwise coiling. E and F: cv. Ghor leaf and burr. G: cv. Borung burr. H: cv. Cyfield burr. I: diagrammatic T.S. of coil edge. J: cv. Cyprus seed. K: cv. Cyfield seeds. L: flower. M: developing fruit (hairs on leaves and burrs, except M, not shown).

variable burr types with spines strongly appressed or not so. Mainly clockwise, some anticlockwise, coiling. Burrs of this cultivar comparable in size with cv. Cyprus and cv. Jemalong: 7-10 mm high \times 4½-6 mm wide.

cv. Cyprus: burrs with strongly appressed spines, clockwise coiling. Indistinguishable botanically but earlier-flowering than similar types in cv. Hannaford.

cv. Jemalong (previously '173') large purple central ellipsoidal leaf mark, burrs with strongly appressed spines, anticlockwise coiling.

cv. Cyfield: a spineless cultivar with large pods (6-11 mm high), large seeds (up to 4 mm long), and both clockwise and anticlockwise coiling burrs.

cv. Borung: small burrs (4-6 mm high) with 2-3½ anticlockwise coils, short spines, 3-4 fruits per raceme.

cv. Ghor: leaves with an upper central yellow mark sometimes bordered with purple-brown. Burrs large, woody, anticlockwise coils, large spines up to 3½ mm long, not appressed, seeds large.

Distribution: *M. truncatula* was naturalised in other states before the introduction of the cultivars. In PERTH there is only one specimen of a spiny barrel medic—from Hopetoun in 1932, which predates the introduction of the spiny cultivars, and a spineless one from Ravensthorpe in 1963 pre-dates the introduction of cv. Cyfield. Despite the lack of herbarium records, it is thought that the species was naturalized over a wide area: Merredin, Leonora, Kalgoorlie, Salmon Gums, before the 1950's (Quinlivan, pers. comm.).

Naturalized material from cv. Hannaford, Cyprus, and rarely Jemalong, is common in the drier cereal and sheep areas, particularly from Merredin to Southern Cross but may also be found along roadsides as far north as Shark's Bay and Laverton and south east to Salmon Gums. The other cultivars, Cyfield, Borung and Ghor, are recent registrations as yet little used in Western Australian agriculture, and not recorded from naturalised populations.

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13.—Sand Fulgurites from Western Australia

by J. E. Glover¹

Manuscript received 19 February 1974; accepted 19 March 1974

Abstract

Fulgurites have been recovered from sand at Willetton, East Victoria Park and Coopers Sandpit, Canning Vale, all near Perth, and from Thangoo Station, near Broome. The Willetton material consists of tube, wall and flange fragments of very light grey vesicular lechatelierite having a refractive index of 1.461 and a silica content of 99.4%. Partly fused quartz grains are embedded in the rough dull outer walls, but are absent from the botryoidal, shiny, inner surfaces. The data accord with an origin due to fusion of sand by lightning. Irregularly shaped black bodies about one mm in diameter scattered in the glass are higher in Fe_2O_3 , TiO_2 and MnO_2 than surrounding lechatelierite and probably represent glass stained by oxides from heavy minerals in the parent sand. The other fulgurites resemble the Willetton material mineralogically and texturally, but contain a higher proportion of cylindrical pieces.

An artificial fulgurite from Cottesloe, consisting of vesicular lechatelierite, is compared with the natural fulgurites. It is broader, lacks a central lumen and flanges, and most of its embedded sand grains are altered to cristobalite.

Introduction

The term fulgurite (from the Latin *fulgur*, lightning) has long been applied to tube-like glassy bodies found on and near the Earth's surface and supposedly formed from sand or rock melted by lightning strikes. The term was first used in 1790 (see Harland & Hacker, 1966) but the bodies had been noted earlier. Many fulgurites have been observed since, and there is a comprehensive discussion by Frondel (1962), who lists the significant references to that time. Artificial fulgurites (Petty, 1936; Fenner, 1949; Raeside, 1968), pseudofulgurites of opal (Read, 1951), and palaeofulgurites (Harland & Hacker, 1966) have also been described.

In Australia, fulgurites and possible fulgurites are known from Moreton Island and Springsure, Queensland (Connah, 1947; Fenner, 1949), Bondi and Macquarie Harbour, New South Wales (Baker, 1959), numerous localities in western Victoria (Fenner, 1949; Beasley, 1963), Oodnadatta, Farina and Mt Remarkable, South Australia (Fenner, 1949), Tempe Downs, Northern Territory (Baker, 1953a), and several localities in the Yilgarn Block, Western Australia (Simpson, 1931; Trendall, 1964). Artificial fulgurites from Cottesloe and Welshpool, Western Australia, caused by high voltage electric

currents, were collected by Professor E. de C. Clarke and described by Fenner (1949). Previously undescribed natural fulgurites from Thangoo Station, southeast of Broome*, and from Kent Street, East Victoria Park†, about 5 km southeast of Perth, have been recognized in the rock store of the Geology Department, University of Western Australia.

This paper describes lechatelierite fragments discovered by the author at Willetton and at Coopers Sandpit, Canning Vale, both in the Perth area, and also describes the fulgurites from Thangoo Station and East Victoria Park in the Geology Department repository. The material is compared with the artificial Cottesloe fulgurite**, for which some new data are given, and the West Popanyinning fulgurite of Simpson††. It is shown that all the newly described material can be categorized as classic tubular or sand fulgurites and that they resemble the West Popanyinning fulgurite, for which an origin by lightning fusion of sand is accepted.

Location and stratigraphic position of the fulgurites

Some five hundred fulgurite fragments were recovered from a cleared area on the southern edge of Leach Highway where it joins High Road, Willetton, about 10 km southsoutheast of Perth, and one fulgurite fragment was collected from Cooper's Sandpit in Ranford Road, Canning Vale, about 17 km southsoutheast of Perth (see Fig. 1). At each locality the material was in a fixed dune of the Bassendean Dune System of McArthur & Bettenay (1960). The dunes had been cleared of vegetation and soil to a depth of 30 cm or more, and it is not known whether the clearing, or earlier movement in the dune, caused the fulgurite fragmentation. The abundant Willetton material is being exposed by deflation, because more is found with succeeding visits. The smaller flake-like fragments are probably moved fairly easily by the wind. The Willetton exposure will be overbuilt shortly, and the discovery site at Coopers Sandpit has already been excavated and destroyed.

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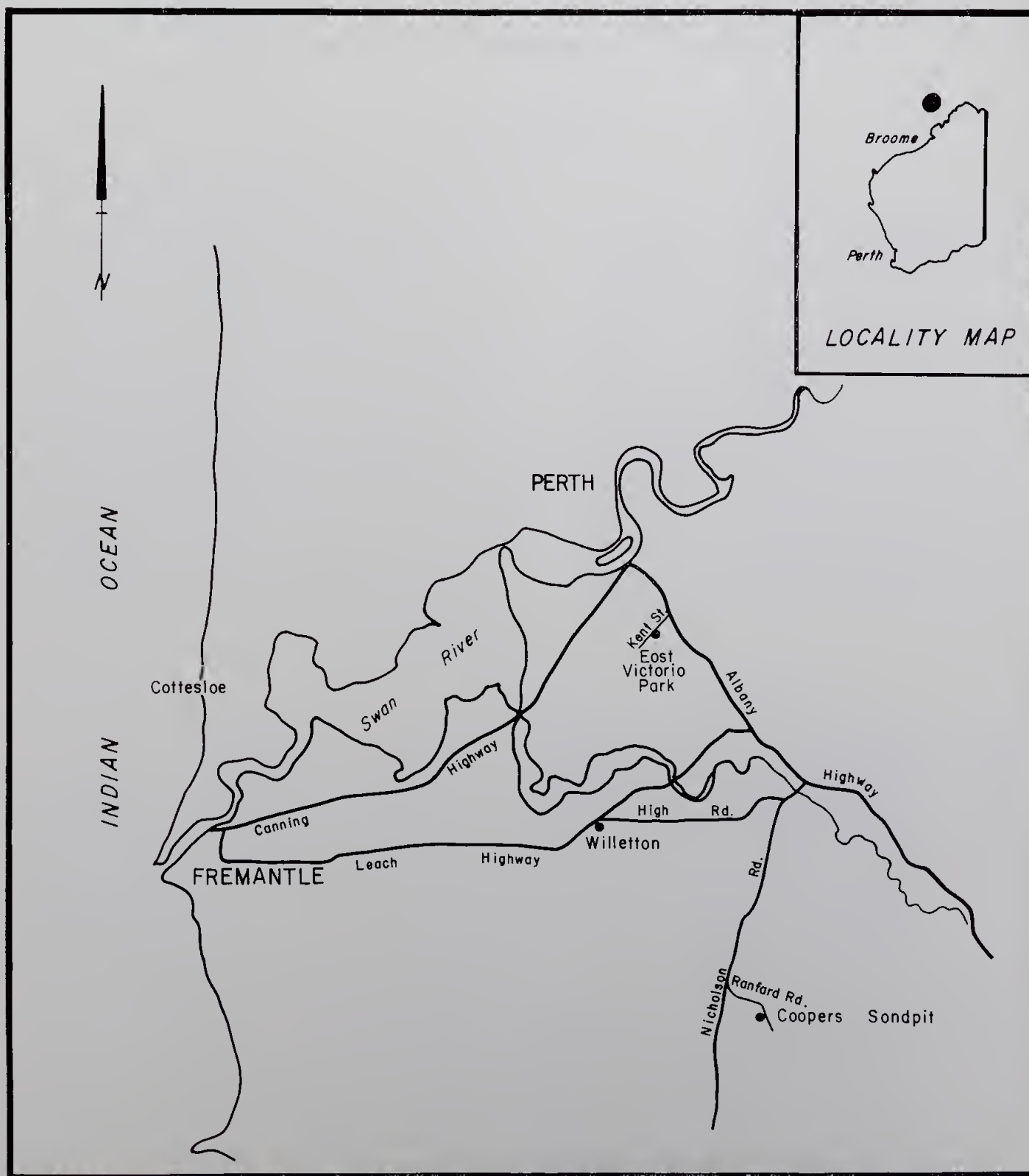


Figure 1.—Map of the Perth area showing fulgurite localities. Scale: 10 km = 6.3 cm.

The East Victoria Park material is recorded in Geology Department files as having been presented by Mr H. R. Gildard, of 80 Kent Street, in 1935. It was said by Mr Gildard to have been dug out of a hole about 2 metres below the surface of his backyard, and to have been in approximately a vertical position. About 30 centimetres were recovered. The map of McArthur & Bettenay (1960) shows that the Kent Street specimen, like the Willetton and Canning Vale material, was in sand of the Bassendean Dune System.

The Thangoo fulgurite was presented to the Geology Department in 1958 by Dr P. E. Playford and is understood to have come from a vegetated sand dune on Thangoo Station, southeast of Broome.

Petrology

The colours and corresponding numerical designations used below refer to the Rock-color Chart distributed by the Geological Society of America (Rock-color Chart Committee, 1963).

Petrography of the Willetton material

About 100 grams of fulguritic material has been collected at Willetton*. Some of the 500 fragments consist of small tubes and some of compressed, highly contorted envelopes open along one or two edges, the latter probably representing broken portions of prominent flanges. Most of the Willetton material, however, encloses no central space and comprises wall fragments about one mm thick and up to about three square cm in area (Fig. 2). All fragments have shiny, somewhat botryoidal inner surfaces and contrasting, dull, jagged exteriors embedded with white, rounded, and subrounded sand grains. The mineral comprising the walls is very light grey (N8) glass with numerous bubbles and a few irregularly shaped, widely dispersed black bodies about one mm in diameter.

Under the microscope the fragments are seen to consist mainly of colourless vesicular glass with bubbles ranging from 0.001 mm to 0.04 mm in diameter. The bubbles fall into two categories. The small cavities that have not been breached during sectioning are apparently gas-filled, and their very low refractive index relative to the surrounding glass is emphasized by their black margins. The larger cavities have been breached and filled with a medium of refractive index 1.54, and these cavities show no black borders. Bubbles tend to be oriented with their long axes normal to the plane of the fulgurite fragment, or to the lumen where present. Most of the bubble cavities are clear, but a few contain some finely divided, indeterminate pale brown mineral. The photomicrograph illustrating the texture of the fulgurite (Fig. 3) bears a striking resemblance to that used by Julien (1901, Fig. 2) in his illustration of a Polish sand fulgurite.

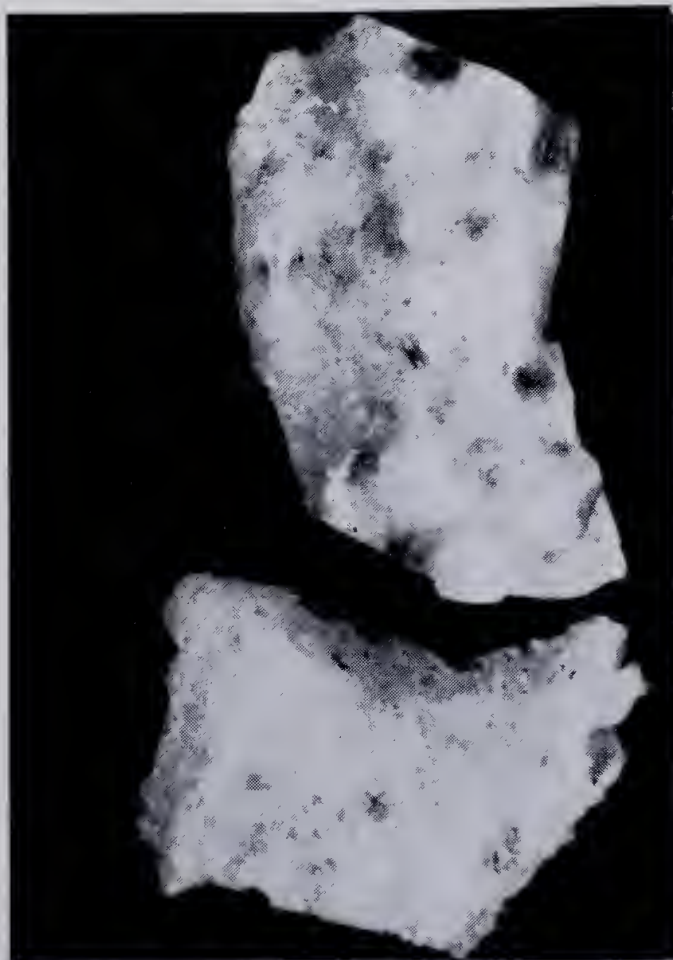


Figure 2.—Fragments of the Willetton lechatelierite, showing (top) the shiny somewhat botryoidal inner surface, and (bottom) the dull rough outer surface. Note the small black portions. The upper fragment is about 2 cm long.

The glass shows two types of boundary in transverse section. One boundary, corresponding to the inner surface, is smooth, and the other, corresponding to the rough dull outer surface, is uneven. The glass toward the uneven boundary commonly has a rather granular texture and locally grades into faintly anisotropic material. Discrete sand grains are embedded in the outer wall, but are not shown in Figure 3. These grains have an unusual appearance under the microscope and commonly consist of biaxial quartz with curved cracks filled with glass. Some individual grains range from an intimate, turbid mixture of quartz and glass on one side, to clear colourless glass on the other.

The refractive index of the glass measured with sodium light is $1.461 \pm .002$, close to that given by Winchell & Winchell (1956, p. 250) for lechatelierite, and within the range of values reported by Frondel (1962, p. 322) for fulgurite glasses.

The black bodies visible in handspecimen are formed of irregularly shaped, brown to black opaque cores and concentrations of wisps that grade outward, with increasing translucency, into brown and pale brown glass. Black bodies of about the same size and distribution are

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evident in some fulgurites photographed by Fenner (1949), notably those from South Australia. They have been mentioned by other authors (see, for example, Petty, 1936, p. 191 and Frondel, 1962, p. 322), and Simpson (1931, p. 146) refers to "small areas . . . darkened by the presence of iron silicate, etc." They are evidently common in tubular sand fulgurites, but have excited little comment or investigation.



Figure 3.—Photomicrograph of thin section of fulgurite from Willetton. The smooth inner surface is on the left, and contrasts with the rough outer surface on the right. Large vesicles tend to be elongated normal to the lumen, and small bubbles show up as almost solid black circles. Length shown = 2 mm.

Chemistry of the Willetton material

The Willetton glass is lechatelierite consisting of 99.4% SiO_2 , with small amounts of titania and other oxides (see Table 1 for comparative analyses of Western Australian glasses). To establish the nature of the scattered black bodies some of the glass was crushed and black material was handpicked for analysis. Few of the selected crushed fragments consisted of pure black material, and most were contaminated by at

least an equal volume of light grey glass. X-ray powder pattern photographs showed no lines, confirming the impression gained from microscopic examination that the black material is not crystalline. Comparative analyses of the dark concentrate and the light grey glass of the fulgurite by the atomic absorption spectrometer showed that TiO_2 was concentrated in the dark material by a factor of 2, Fe_2O_3 by a factor of 4, and MnO_2 by a factor of more than 6. These oxides were probably supplied by heavy minerals in the fused sand, and doubtless account for the dark colour.

Table 1

Analyses of Western Australian vesicular and scoriaceous glasses

	Willetton*	West Popan-yinning**	Widgie-mooltha†	Widgie-mooltha††
SiO_2	99.4	88.46	64.9	59.2
TiO_2	0.14	0.46	0.06	n.d.
Al_2O_3	0.09	6.69	9.12	13.0
Fe_2O_3	0.012	1.16	5.75	9.4
Mn O	0.002	Tr	0.02	n.d.
Mg O	0.0795	0.17	3.27	5.7
Ca O	0.02	0.17	12.0	10.4
Na_2O	0.011	0.01	2.05	2.0
K_2O	0.02	2.68	1.64	1.1
P_2O_5	n.d.	n.d.	0.15	n.d.
Cu	n.d.	n.d.	n.d.	0.01
H_2O^+	n.d.	n.d.	0.41	n.d.
Loss on ignition	0.02	....	....	....
	99.8	99.80	99.37	100.8
	(approx.)			
	$N = 1.461$	$N = 1.465$		
		$G = 2.21$		

* Analyst Labtech Pty Ltd, Job No 5917, Rack No 6250 (combined XRF, Atomic absorption)

** Reported by Simpson (1931, p.146)

† Specimen R851, "fulgurite slag", Widgiemooltha area, Analyst Govt. Chem. Lab, reported by Trendall (1964, p.7)

†† "Fulgurite slag", near Paris Goldmine, Widgiemooltha area, Analyst C. E. S. Davis, reported by Trendall (1964, p.7).

The Willetton sand

The fulgurites are mainly found in white to pinkish grey (N9-5YR8/1) sand near the crest of a fixed dune, but winds sweep the bare patch and small fragments are also found in nearby orange sand (see below). The white sand is well sorted ($\text{So} = 1.22$) and consists mainly (about 99.6%) of subrounded to well-rounded quartz grains with a median diameter of 0.28 mm. Some of the quartz is practically free of inclusions, and some contains minute inclusions of black opaque minerals, leucoxene, rutile, tourmaline, hypersthene, zircon, probable apatite and fluid. Heavy minerals separated in bromoform from a sample of sand made up 0.44% by weight and consist mainly of ilmenite and leucoxene (see Table 2).

Also near the top of the dune, and containing a few small fulgurite fragments, is some very pale orange to greyish orange (10YR8/2-10YR 7/4) sand. This sand is as well sorted as the white sand, yielded an almost identical crop

of heavy minerals (0.45% by weight), and seems to differ only by the discontinuous film, apparently of limonite and hematite, on many of the grains. The concentration of fulgurite fragments (particularly the larger ones) in the white sand, and the presence in the glass of embedded white grains but not of orange-coloured grains, shows that the fragments originated in white sand and were recently blown into the orange-coloured sand.

Table 2

Mineralogy of white sand from Willetton

Mineral	Wt%
Quartz	99.56
Ilmenite	0.25
Leucosene	0.09
Magnetite	0.03
Staurolite	0.02
Kyanite	0.02
Zircon	0.01
Garnet	Trace
Tourmaline	Trace
Rutile	Trace
Spinel	Trace
Andalusite	Trace
Unknown	Trace

Mineralogical source of the Willetton fulgurites

The white sand of the Willetton area would yield a highly siliceous glass if fused and chilled, and the high silica content of the Willetton fulgurites, together with their incorporated partly fused quartz grains, accords with such an origin. TiO_2 (0.14%) is fairly close to the amount calculated for the sand from its mineralogy (0.22%), but Fe_2O_3 (0.012%) is significantly lower than the sand mineralogy would indicate (0.17%). The reason for this apparent discrepancy can only be speculated: iron may have migrated quickly when the quartz fused, or may have been leached out of the glass later.

The Coopers Sandpit material

The material from Coopers Sandpit, Canning Vale*, consists of an irregularly flanged tube about 2.5 cm long with an inner diameter of about 0.7 cm and a variable outer diameter of about 0.9 cm (Figs. 4, 5). The outer walls are rough and uneven, and contain numerous, embedded, white to very light grey (N9 to N8), rounded to subrounded, fine to medium-grained sand grains. The inner walls consist of smooth, shiny, somewhat botryoidal very light grey (N8) glass with a few black stains about 1 mm in diameter. The weight of the specimen is 0.8 grams.

A small fragment was broken from the tube, crushed, and examined microscopically in oils. The material is highly vesicular colourless glass with a refractive index of $1.461 \pm .002$.

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Figure 4.—Side view of fulgurite fragment from Coopers Sandpit, Canning Vale. Note the rough dull outer surface, and smooth bright inner surface. Length of fragment 2.5 cm.

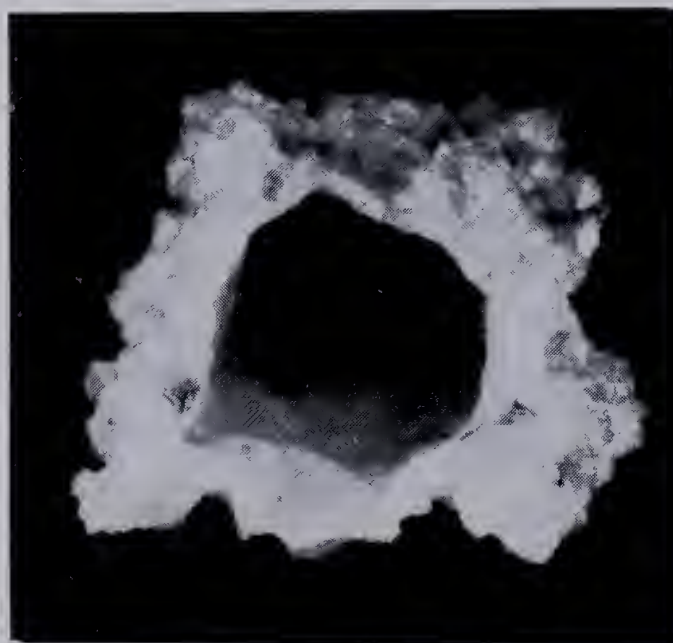


Figure 5.—End-on view of fulgurite fragment from Coopers Sandpit, Canning Vale. The rough, flanged exterior contrasts with the smooth lumen. The lumen has a diameter of about 7 mm.

The East Victoria Park material

This material consists of a tube 5.5 cm long and 1.5 cm wide, with walls about 1 mm thick. The outer surface is light grey (N7) and has a rough feel, but is only slightly flanged. Pale yellowish orange (10YR8/6) to very pale orange (10YR8/2) rounded to subrounded quartz sand grains embedded in the light grey glass give it a speckled greyish orange appearance. The inner surface of the tube consists of shiny, smooth but crinkled, very light grey (N8) to light grey (N7) glass. Irregularly shaped black bodies or stains about one mm in diameter are present in the glass, and can also be seen on the outside. In addition to the cylinder there are thirteen small fragments, and in all, the specimen weighs 6.2 grams.

Some of the material was powdered and examined microscopically in oils. It consists mainly of finely vesicular colourless glass with some attached quartz grains. The refractive index of most of the glass is very close to $1.461 \pm .002$, but the index is not completely uniform, and a range up to $1.463 \pm .002$ was noted.

The Thangoo material

The Thangoo material consists of numerous small fragments and two tubular fragments, each about 5 cm long and 2 cm wide, with walls about one mm thick. The outer surfaces are very light grey to light grey (N8 to N7), with a rough feel, but have developed only incipient flanges. These surfaces consist mainly of very well rounded to subrounded sand grains up to one mm in diameter. The inner surface is made up of light grey to medium grey (N7 to N5) shiny botryoidal glass, and a few small irregularly shaped black bodies can be seen in it. The total weight of the material is 27.2 grams.

Microscopic examination of crushed material in oils shows that it consists mainly of colourless, finely vesicular glass with attached quartz sand grains, some of which are turbid where they pass, via an intimate quartz-glass mixture, into clear glass. The glass ranges in refractive index mainly between $1.458 \pm .002$ and $1.466 \pm .002$, and most of it is close to $1.461 \pm .002$.

The bubble cavities are generally clear. A thin section of part of the fulgurite, however, shows bubbles filled with opaque aggregates of a very finely divided mineral that is greyish yellow (5Y8/4) to light brown (5YR5/6) in reflected light. The mineral may have been introduced, but its origin is uncertain.

Main features of the sand fulgurites: a summary

All the material is fragmentary, and has been derived from longer tubes, whose original shapes and dimensions are unknown. The fragments have many common features. All the

glass is finely vesicular, is light grey to very light grey (N7 to N8), and contains scattered, irregularly shaped black bodies or stained portions about one mm in diameter. Each fragment has one dull surface with embedded sand grains or partly vitrified sand grains, and one crinkled shiny or vitreous surface. On the dull or outer surface there are incipient to strongly developed winglike projections or flanges parallel to the length of the tube. The refractive index ranges from 1.458 to 1.466, but the most common value is 1.461.

A fragment of the West Popanyinning fulgurite described by Simpson is available for comparison (University Geology Department No. 12158). Its walls have the same structural and textural characteristics, including sand grains embedded on the outside, and projecting flanges. The colour of the shiny botryoidal glass of the lumen is light grey (N7) with scattered black spots, and the refractive index of the highly vesicular glass, according to Simpson (1931) ranges from 1.463 to 1.467 with a mean of 1.465. The West Popanyinning fulgurite was found in clayey, feldspathic sand and is more aluminous and less siliceous than the fulgurites described above. In other respects, however, it is very similar, and clearly deserves to be grouped with them.

Cottesloe artificial fulgurite

One specimen of the artificial fulgurites collected from Cottesloe by Professor E. de C. Clarke and described by Fenner (1949) is housed in the Geology Department, University of Western Australia (Fig. 6). The material formed from the fusion of sand by shorting of electric mains, and is likely to have been subject to a lower voltage maintained for a longer time, than natural fulgurites. The specimen is 18.5 cm long, about 8 cm wide at its widest, and weighs 723.4 grams. The colour of the glass ranges from medium to medium dark grey (N5 to N4), but because the outer surface is encrusted with white to very light grey (N9 to N8), well-rounded sand grains, the overall colour of parts of the outer surface is light grey (N7). The central part is made up of highly vesicular glass with some large cavities, but there is no central lumen. Under the microscope the glass is colourless with dark grey schlieren: its refractive index ranges from $1.461 \pm .002$, which is fairly common, to $1.466 \pm .002$. Most of the sand grains of the outer surface have been pseudomorphed by aggregates of cristobalite showing "tile" structure under the microscope. The identity of the cristobalite has been confirmed by X-ray powder photography.

Fenner, who examined several artificial fulgurites, including the Cottesloe specimen, noted that they differ in several respects from natural fulgurites. The tube is thicker and may be practically filled with glass, and the subparallel flanges are absent. It can be added that cristobalite, present in the Cottesloe specimen, was not observed in the natural fulgurites described in this paper.



Figure 6.—Artificial fulgurite from Cottesloe. The light grey areas contain embedded sand grains, most of which have been altered to cristobalite. Length of specimen 19.5 cm.

Origin of the Western Australian sand fulgurites

The arid climate and sparse vegetation in parts of Australia have probably favoured the preservation and allowed the exposure of many kinds of natural glass that tend to be destroyed or covered with soil in more humid and highly vegetated countries. The sand or tubular fulgurites described above can generally be distinguished by their shape, texture, composition or geological setting from other Australian natural glasses. The latter include volcanic glass; drift pumice from outside Australia (Sutherland, 1965; Bryan, 1968); pseudotachylite from fault zones (not uncommon, but poorly documented: see Francis, 1972, p. 35); australite glass of extra-terrestrial origin (Baker, 1959); glass formed by meteorite impact (Spencer, 1933); and glasses formed by burning coal or vegetation (Baker & Gaskin, 1946; Baker, 1953b, 1964; Trendall, 1964). It should be said that there is no unanimity in applying the origins just listed to some of the glasses, and in particular the origin

of so-called Darwin glass is by no means finalized. Trendall (1964) erected an additional category, that of "fulgurite slag", for material formed by the fusion of soil by lightning, and he included in it the scoriaceous slaggy material collected on the Yilgarn Block (see Table I) and some of the glasses for which an origin due to melting by fire had been suggested by others. Subsequent evidence however (Trendall *pers. comm.*) throws doubt on the origin of the Yilgarn slags. As indicated, the material described in this paper is rather different: it adds nothing to our knowledge of the other glasses, and they will not be discussed further.

The fused sand grains and high silica content of the newly described Western Australian fulgurites practically prove derivation from the sand in which they were found. The sand was almost certainly melted by lightning because temperatures reached in lightning flashes (Loeb, 1949, p. 22; Schonland, 1964, p. 98) are far higher than the 1800°C supposedly necessary for quick fusion of quartz (Rogers, 1946), whereas temperatures attained by natural fires seem normally to be over 1000°C lower (see Beadle, 1940). Moreover, these fulgurites are similar in form and texture to that described by Simpson (1931), which was recovered from sandy ground shortly after a lightning strike. Simpson's fulgurite extended downward for about a metre, and seems to have had the same orientation as the Kent Street fulgurite. A similar fulgurite, collected after an observed lightning strike, was recorded by Fenner (1949, p. 128). These examples independently supplement extra-Australian reports of fusion by lightning (Pfaff, 1822; Wicke, 1859; Van Bastelaer, 1883; Wood, 1910) and together constitute an impressive body of evidence.

A great deal has been written about the tubular, branching shape of sand fulgurites. The central lumen and numerous vesicles are commonly attributed to the thermal expansion of air and vapour from water trapped in the sand, and any flattening of the tube to the pressure of the surrounding sand while the glass was plastic. The abundant Willetton material seems to represent fragments of highly flanged tubes whereas the other fulgurites consist of broken tubes on which the flanges were less prominent. The tendency for vesicles to be elongated normal to tube walls fits the concept of outwardly moving gas during thermal expansion.

It has been suggested (Lewis, 1936, p. 57; Fenner, 1949, p. 138) that fulgurites owe their shape to fusion of sand around the roots of trees or plants struck by lightning. The root would be carbonized and might, with downward burning, smoulder to ash. Trendall (1964) discussed this aspect, and concluded that most tube fulgurites formed around roots. The fulgurites described above provide no evidence on this point.

Conclusions

The fulgurites recorded in this paper are of the classical tube or sand fulgurite variety, and formed from sand fused by lightning. The abundance of lightly vegetated, sandy country in Western Australia practically ensures that many similar fulgurites remain to be found.

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14.—Disjunct plant distributions on the south-western Nullarbor Plain, Western Australia

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Abstract

Recent collections of plant specimens from several isolated dune systems on the coast of the Great Australian Bight between Point Culver and Twilight Cove, Western Australia, are discussed. These siliceous cliff-top dune systems are colonised by species regarded as typical of the "quonkan" (siliceous sand plain) of the south-west botanical province of Western Australia. These species are not found on the calcareous soils of the Nullarbor Plain. The disjunct distribution patterns of some species are considered to have resulted from disruption of a continuous vegetation belt that developed on the exposed sand deposits of the continental shelf, during the last period of marine regression, in the Late Pleistocene. Species similarities between south-eastern and south-western Australia are discussed in the context of these disjunct distribution patterns.

Introduction

Botanically, the Nullarbor Plain is defined as the tree-less (*nulla, arbor*) area on the limestone plain in central, southern Australia, north of the Great Australian Bight (Delisser 1867). The vegetation of the region consists of low scrub, dominated by members of the Chenopodiaceae (Willis 1959). However the extension of the use of the sobriquet to encompass the whole of the region containing the horizontally-bedded Miocene limestones has become a common practice* (Jennings 1963, Dunkley 1967, Parsons 1970). The restricted botanical region (Fig. 1) lies to the east of the areas discussed here, and has little bearing on this discussion.

In the south-western part of the limestone plateau, there are several isolated areas on or near the coast where the limestones are covered with younger deposits of aeolian calcarenite (Lowry 1970) and unconsolidated siliceous sand dunes. These 'sand patches' are situated at Point Culver, at Toolinna (north-west of Point

Culver), south-west of Point Dover, and at Twilight Cove (Fig. 3 in Jennings 1967). Two of these areas, Toolinna and Twilight Cove (Fig. 2), have been visited by the author. On those occasions, plant specimens were collected, data on the vegetation recorded and soil samples obtained. Twilight Cove was visited in December 1972, August and October 1973, while Toolinna was visited only in October 1973. The visits were made in order to collect specimens for a taxonomic revision of *Adenanthos* Labill. (Proteaceae).

Some of the species collected on the sand patches had not previously been recorded east of Israelite Bay or Mount Ragged (Fig 2). These plants are regarded as typical members of the *quonkan** (Brooks 1894), or flora of the siliceous sand plain, that is found between Esperance and Israelite Bay. Their occurrence on these isolated dune systems presents an interesting phyto-geographic problem, relating to the history of both land forms and vegetation in the areas adjacent to the Great Australian Bight.

Vegetation zones of south-western Australia

The South-West Botanical Province of Western Australia as defined by Diels (1906) is noted for the great diversity and the high rate of endemism that the flora exhibits (Burbidge 1960, Beard 1969, Marchant 1973). The province has been variously delimited, but generally covers a triangular-crescentic area bounded by the coast of Western Australia, and by a line extending from Shark Bay to Israelite Bay, corresponding approximately to the 175 mm winter isohyet (Gardner 1956) (Fig. 1). While most definitions of the region depend on climatic and botanical data (Marchant 1973), in certain areas it is possible to relate these data to geological information. Thus in the south-eastern region near Israelite Bay, the province terminates at the boundary between the rocks of the Precambrian Shield and the Tertiary sedimentary rocks of the Nullarbor Plain (Fig. 2).

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* Lowry (1970) used the name "Bunda Plateau" to cover this geological area as he considered the term "Nullarbor Plain" too useful to modify its original use. However common usage has already expanded the application of the name and as it is employed by Parsons (1970) in the widest sense, it is used herein to encompass the whole of the limestone region.

* This was spelt "quowcken" by Brooks, but should read "quonkan" (Mrs. A. E. Crocker, pers. comm.). *Quonkan* is an aboriginal name for the vegetation, composed mainly of low sclerophyll shrubs, that occurs on siliceous sand plain in this area (Brooks 1894). A similar word, "guangan", was used in areas north of Perth according to Drummond (Erickson 1969).

Beard (1973) has included the whole of the lowland plains, south of Point Culver, within the south-west province, as well as the region, underlain with limestone, that surrounds Mount Ragged and the Russell Range (Fig. 2). This latter area (Beard's "Cooper System") is placed in the South-West Interzone by Burbidge (1960), who also included most of the Eyre zone (Fig. 1) of the south-west province (Diels 1906) in that Interzone. Whatever the limits of these ill-defined zones and provinces, the areas under discussion are usually placed outside the south-west province within the Eremean province.

The flora of the south-west province is adapted to soil of extremely low fertility, and low calcium status (Seddon 1972), and some species may be extremely sensitive to changes in edaphic propensities (Diels 1906, Speck 1958).

Geology and geomorphology

The deposits of Miocene limestone that comprise the Nullarbor Plain (*sensu lat.*) extend from Mount Ragged in Western Australia, to Penong in South Australia (Fig. 1) and inland toward the Forrest Lakes and the Great Victoria Desert (Lowry and Jennings, 1974). Along the coast of the Great Australian Bight, there is an almost unbroken line of cliffs, about 80 m high, formed of horizontally-bedded limestones. There are a few areas of low-lying coastal plain, particularly the Roe Plains (Fig. 1) that disrupt this cliffed coastline.

Near Point Culver, the Baxter Cliffs swing inland to form the Wylie Scarp. A narrow coastal plain, the Israelite Plain (Lowry 1970) which is much lower than the main plateau of the Nullarbor (Fig. 2) lies between the Scarp and the coast. The Israelite Plain is composed of vegetated sand dunes with interdunal salt flats and lagoons. Lowry (1970) indicated that these dunes were deposited in the Pleistocene after the formation of the Wylie Scarp by marine erosion. At its northern end the dune systems converge on the emerged cliffs, and dunes found on the top of the cliffs, overlying the Miocene limestones (Jennings 1967), form the Point Culver sand patch (Fig. 2).

A similar situation is found at Twilight Cove. The lowland dune systems of the Roe Plains meet the cliffs where they swing inland to form the Hampton Range, and cliff-top dunes are situated on the plateau about 80 m above sea level (Jennings 1967). The Roe Plains sand deposits overlie a thin layer of Pleistocene calcarenite (Lowry 1970) and thus are probably late Pleistocene deposits, similar in age to those of the Israelite Plain.

Between Twilight Cove and Point Culver, to the south-west, the coastline is formed by the almost vertical Baxter Cliffs (Lowry 1970) which vary in height from 60 m to 100 m. At Toolinna there is no coastal lowland, but a dune system is isolated on top of the cliffs. A further small set

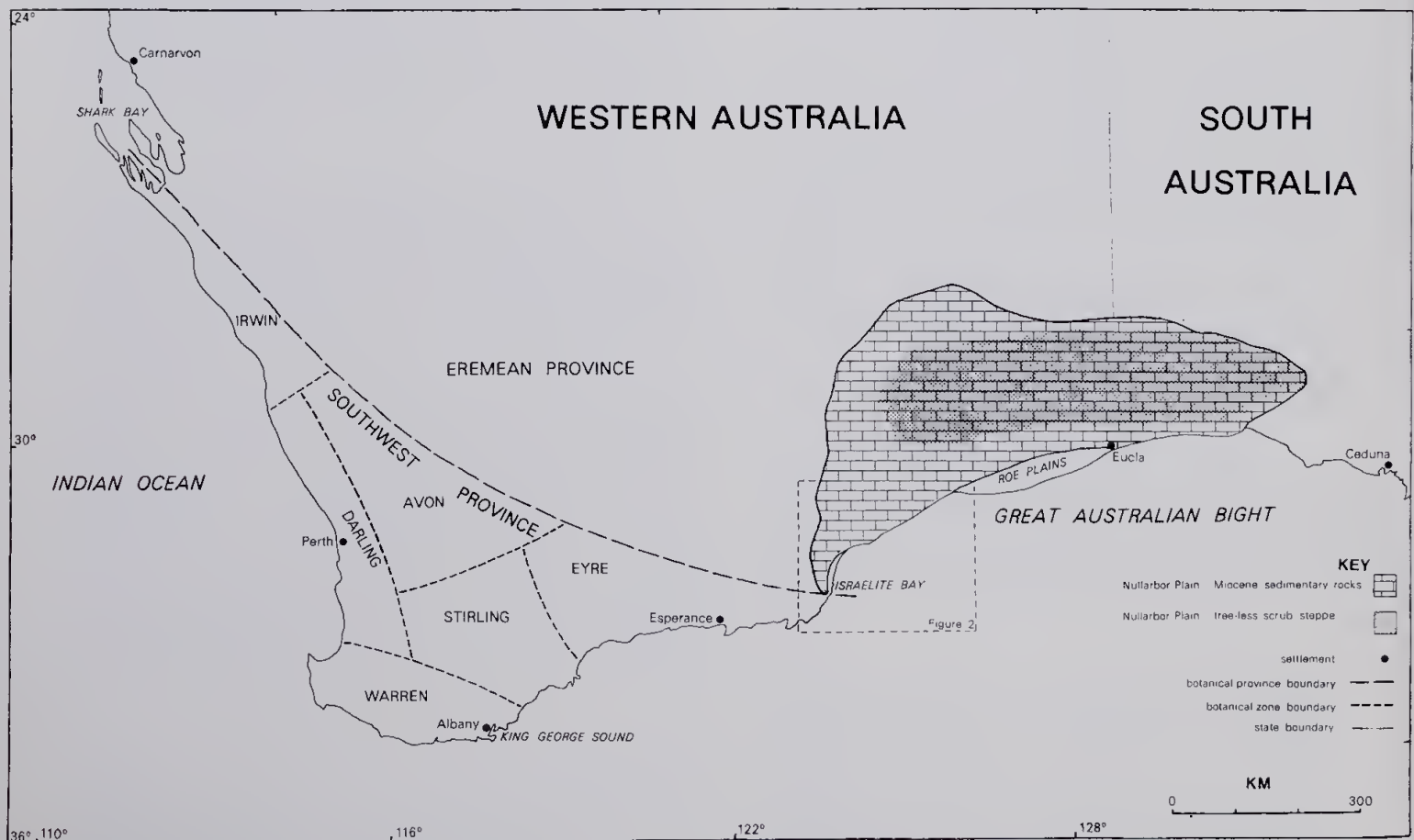


Figure 1.—South-western Australia, showing the relative extents of the tree-less scrub steppe and the Tertiary sedimentary deposits. The approximate boundaries of the botanical provinces and zones of Western Australia are indicated (Diels 1906, Gardner 1956).

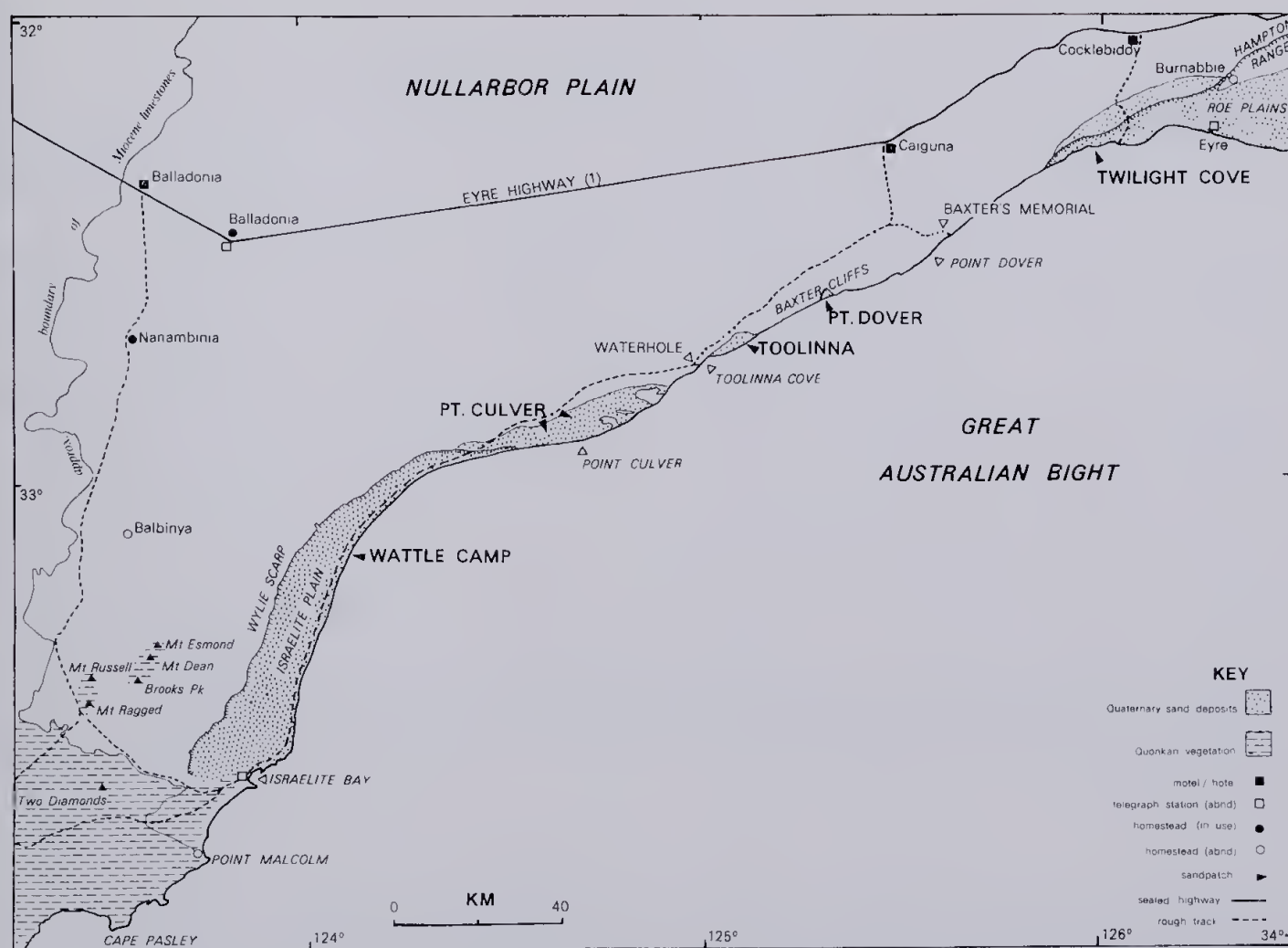


Figure 2.—South-western Nullarbor Plain showing the locations of the siliceous sand dunes discussed in the text.

of cliff-top dunes is isolated south-west of Point Dover*, between Toolinna and Twilight Cove. Again there is no associated coastal lowland (Jennings 1967). All the systems consist of sand deposits up to, or in some places more than 30 m deep.

Jennings (1967) suggested that these isolated dunes on the cliff tops were formed during a period of marine regression, when a very narrow coastal plain was exposed south-east of the present cliffs. The dunes could have been emplaced when ramps of wind-blown sand were formed against the cliffs, in a manner similar to the present situation at Point Culver and Twilight Cove. Subsequent marine transgression would have eroded away the ramps and isolated the deposits on the plateau. The maximum of last marine regression occurred during the late Pleistocene glacial period, about 20,000 years B.P., when sea levels were about 100 m lower than present datum (Jennings 1971). During that glacial period conditions suitable for dune

emplacement would have occurred. These isolated sand patches could date from the late Pleistocene or early Holocene, though a greater age is possible if dunes were emplaced in previous glacial epochs (J. N. Jennings, pers. comm.). As the dunes at Point Culver and Twilight Cove are active and mobile at the present time, it is probable that dune emplacement will only take place when the coastal lowland south of the cliffs is very narrow; perhaps only a few kilometres wide. This dune building on the cliff-tops may not have taken place until sea levels were very close to the base of the Baxter Cliffs. This would mean that the deposits may be 10 000-6 000 years old. (Hydrographic charts for the coast in this region are incomplete. Several kilometres from the cliffs the ocean depth is about 40 m. Dates were derived using this depth and reconstructed sea-level curves for the Australian region (Thom and Chappell 1975).)

Jennings (1967), Lowry (1970) and Parsons (1970) indicate that there are aeolian calcarenite deposits underlying the sands at Twilight Cove and on the Roe Plains. Parsons (1970) stated that "sheet limestone" was encountered at 0.66 m in a profile at Twilight Cove. While Jennings (1967) stated that the dunes of the western Roe Plains, immediately adjacent to

* Jennings (1967, Fig. 4c) located this area about 2 km south-west of Point Dover at 32° 31' S, 125° 30' E. An examination of photomosaic maps revealed that the dunes are situated 32° 37' S, 125° 15' E about 30 km south-west of the point and nearer to Toolinna.

Table 1

*pH of soil and proportions of calcium carbonate in sand samples from cliff-top dunes.**

Sample number	Location	% CaCO ₃ (ppm Ca ⁺⁺)	pH
TWS 1	dune surface ; on cliff top at Twilight Cove, before descending scarp, c.20 km south of Cocklebidy	nil	5.7
TWS 2	as TWS 1	nil	5.9
TWC 3	1m below TWS 2, in profile	nil	5.9
AFOR	dune surface ; about halfway through dune system at Twilight Cove, c.15 km south of Cocklebidy	nil	5.6
AFOR 1	as AFOR	nil	5.7
HYB	as AFOR	nil	6.0
TOO 1	dune surface, Toolinna sand patch	nil	6.0
TOO 2	as TOO 1	nil	6.1
TOO 3	as TOO 1	nil	6.1
TOO 4	as TOO 1, from area where sand was only a few centimetres deep, overlying calcarenite	tr. (<15)	5.8
TOO 5	as TOO 1	nil	5.8

* 30 gm sand was analysed by volumetric calcimeter technique for calcium carbonate determination. One part soil and two parts (by volume) 1% KCl were shaken and allowed to stand for one hour before reading pH with a glass electrode and meter. (The pH values obtained using KCl solution are about 1 unit higher than those obtained from moist soil in the field.)

the Twilight Cove sand patch, were calcareous, analysis of samples from the dune surface at Twilight Cove, and from a pit one metre deep, indicate that the sand contains no calcium carbonate (Table 1). It is possible that the dunes east of Twilight Cove are calcareous, but those being considered here are siliceous to a depth of at least one metre. The sand on the beach at Twilight Cove is also siliceous; in the field the author estimated that there was about 5 per cent calcium carbonate (shell fragments) in the sand.

The sand dunes at Point Culver are probably also siliceous (Parsons 1970); this is suggested by the vegetation recorded on the dunes. Coastal sand deposits at Israelite Bay are mainly siliceous. The deposits on the cliff-top at Toolinna conform to the pattern noted; aeolian calcarenite overlain by unconsolidated siliceous sand. Analysis of the samples from Toolinna showed that there was no calcium carbonate present, though one sample (TOO 4, Table 1) had a trace of calcium carbonate. At Toolinna Cove the sand at the base of the cliffs on the very small beach, underwater, appeared to be siliceous. At the cove the cliffs are not precipitous; there is a modern rockfall allowing access to the base of the cliffs and the small sandy beach.

Lowry (1970) noted a further set of "ancient dunes" on the Hampton Tableland, east of Twilight Cove, composed of siliceous sands. These are probably older than the dunes at Twilight Cove and may date from the middle or early Pleistocene.

While there is only a small amount of geomorphological information available for these areas, certain general features should be noted. The sand deposits along the present shores of the Great Australian Bight show substantial differences in calcium carbonate content. At Israelite Bay, and probably also at Twilight Cove, the sands contain only about 5 per cent calcium carbonate. At Eucla (Fig. 1) and at the Head of the Bight, the sands are composed mainly of calcium carbonate particles, with less than 50 per cent siliceous material (Lowry 1970). At present there is an east-west gradient with higher calcium carbonate levels east of the Roe Plains. The extant cliff-top dunes are composed of siliceous sands. Leaching, by rainwater, of sand dunes containing both siliceous and calcareous grains can result in the complete removal of the calcareous material and the production of pure siliceous sand dunes with an underlying layer of calcarenite. Leaching time depends on many factors, especially climate and the original calcium carbonate levels. Thus the problems associated with these dune systems may be more complex than suggested here.

Finally the very extensive dune systems on the coast of the Bight, associated with the Israelite and Roe Plains, and the Head of the Bight suggest that at times of low sea levels the exposed lowland plain on the continental shelf, south of the Nullarbor Plain, was covered with sand dunes that were continuous across the Bight. The isolated cliff-top dunes reinforce this thesis (J. N. Jennings pers. comm.).

Botanical surveys

Edward John Eyre passed along this part of the Australian coast in 1841 (Eyre 1847). He stopped near Twilight Cove, and then he continued along the cliffs to Point Culver, and eventually reached King George Sound. He certainly traversed the Toolinna and Point Culver dune systems but his comments on the vegetation are very short (Eyre 1847) and he did not collect specimens. In 1870 John Forrest explored the route for an overland telegraph line to link Adelaide and Perth. He travelled along the Israelite Plain to Point Culver, but then he passed inland, keeping about thirty-five kilometres from the coast. He returned to the sea at Twilight Cove. Forrest made useful botanical collections between Israelite Bay and Eucla; he certainly collected south of Point Culver and at Twilight Cove. Some of the specimens were described by Mueller including *Adenanthos forrestii* F. Muell. (Mueller 1882).

The telegraph line, which was surveyed by Forrest was completed in 1877, and some of the telegraph operators who had to live in these very isolated areas, collected plants. Some of the settlers, including John Brooks* of Balbinya (Fig. 2) made observations and collections for Mueller (Brooks 1894, Willis 1959).

Very little attention has been given to this region in recent times, probably due to its inaccessibility. The Israelite Plains have never been examined botanically. George, Beard and Parsons have collected at Twilight Cove, while Wilson and Beard have collected south of Caiguna and near Point Dover. There are no records of collections from Toolinna prior to 1973. The first modern collection of plants from Point Culver was made in October 1973 by M. G. Brooker (pers. comm.) Most of the early collections were sent to Mueller and are lodged in Melbourne (MEL.) Recent collections, including those of the author are lodged in Perth (PERTH), Adelaide (AD) (Parsons 1970), and in Herbarium Australiense, Canberra (CANB). No collections are extant for the Point Dover sand patch.

Vegetation of sand patches and surrounding regions

Parsons (1970) discussed the vegetation of the Twilight Cove dune system in some detail. Apart from a brief comment by Beard (1973) concerning the vegetation of the Israelite Plain, and a similar statement by Brooks (1894), no discussions are available that are relevant to the area (Beard 1973). Willis (1959) described the vegetation of the Nullarbor and Roe Plains at Eucla, about 250 km east of Twilight Cove.

The vegetation of the limestone plateau in the area south of the Eyre Highway (Fig. 2) and between Twilight Cove and Mount Ragged consists mostly of dense mallee scrub, interspersed with clay flats that have a flora dominated by

ephemeral plant species (Beard 1973). The scrub is composed of mallee species such as *Eucalyptus cooperana*, *E. oleosa* and *E. flocktoniae*. There is a sparse understorey of calcicole shrubs such as *Halgania lavandulacea*. Some sclerophyll woodland of taller, non-mallee *Eucalyptus* species occurs in areas to the west of Point Culver and towards the Fraser Range (Beard 1973). The vegetation generally is quite uniform, though variations in these basic types do occur with increasing distance from the coast. The vegetation rarely consists of low tree-less scrub dominated by Chenopodiaceae.

The vegetation of the sand patches is very different from that of the surrounding limestone plateau. At Twilight Cove it consists of very open mallee scrub dominated by *Eucalyptus cooperana*, *E. foecunda* and several other *Eucalyptus* species (Parsons 1970). *Callitris verrucosa* also is frequent and dominant in a few areas, where aeolian calcarenite is exposed or close to the surface of the sand deposits. The mallee scrub has an understorey of sclerophyllous shrubs. These are mostly from the family Myrtaceae and include several *Melaleuca* species, *Beaufortia empetrifolia* (Parsons 1970), *Calytrix tetragona* and *Darwinia vestita*. In some places members of the Epacridaceae, such as *Conostephium drummondii* and *Lysinema ciliatum* are common. *Adenanthos forrestii** is the only member of the Proteaceae that attains a dominant position in any area; other members of the family are seldom encountered.

On the sand patch at Toolinna, the *Eucalyptus* species are very much less frequent than at Twilight Cove. There is no mallee scrub on the Toolinna dunes, at least in the areas seen by the author. A few very stunted plants of *Eucalyptus incrassata* and *E. diversifolia* were found. The dominant shrubs are species of *Melaleuca*, with frequent occurrences of *Acacia cochlearis*, *Calytrix tetragona* and *Adenanthos forrestii*. The major difference between the vegetation encountered in this area and that at Twilight Cove is the presence here of *Banksia media*. Tall shrubs, up to 5 m, of this species are scattered throughout the dunes.

According to M. G. Brooker (pers. comm.) the vegetation near Point Culver is dominated by mallee *Eucalyptus* species, including *E. diversifolia*, *E. angulosa* and *E. cooperana*. *Melaleuca pentagona* is the most prevalent undershrub. Members of the Proteaceae are much more abundant than at Twilight Cove or Toolinna, and *Banksia media* and *B. speciosa* are common (Eyre 1847, M. G. Brooker, pers. comm.). *Grevillea oncogyne* is also abundant.

Beard (1973) indicated that the Israelite Plain probably has a vegetation dominated by *Banksia speciosa*; this being the dominant species on the siliceous sands at Israelite Bay. It should be

* Brooks name is occasionally spelt "Brooke"; an error arising from his signature and style of writing. (Mrs A. E. Crocker, pers. comm., Willis 1959).

* Parsons (1970) listed this species as *Adenanthos sericea* Labill., var. *brevifolia* Benth. His specimen (AD 9682090) was redetermined by the author as *A. forrestii* F. Muell.

Table 2

Species present on dune systems on south-western Nullarbor Plain

Species	Western Australia					S. Aust.	Sand Patches			Species confined to siliceous sands
	i	a	d	w	s		PC	TO	TC	
<i>Callitris verrucosa</i> (A. Cunn. ex Endl.) F. Muell.						*	*		*	
<i>Amphipogon turbinatus</i> R.Br.	*	*	*	*	*	cf.	*
<i>Danthonia caespitosa</i> Gaudich.				*		*	
<i>Stipa acrociliata</i> Reader			*		cf.	*	
<i>Gahnia lanigera</i> (R.Br.) Benth.			*	*	*	*	
<i>Lepidosperma drummondii</i> Benth.	*				*	*	*
<i>Schoenus lanatus</i> Labill.		(*)			?	*	*
<i>Schoenus nitens</i> (R.Br.) Poir			*		*	*	
<i>Schoenus pleiostemoneus</i> F. Muell.		*			*	*	*
<i>Lorocarya flexuosa</i> (R.Br.) Benth.						?	?
<i>Stypandra imbricata</i> R.Br.	*	*			*	*	
<i>Tricoryne elatior</i> R.Br.		*		*		*	
<i>Anigozanthos rufa</i> Labill.			*	*			*
<i>Casuarina helmsii</i> Ewart & Gordon			*	*		*	
<i>Casuarina huegeliana</i> Miq.	*	*				*	
<i>Casuarina humilis</i> Otto et Dietr.		*	*	*	*		*
<i>Adenanthos cuneata</i> Labill.		*	*	*	?	*	*
<i>Adenanthos forrestii</i> F. Muell.			*		?	*	*
<i>Adenanthos</i> sp. nov.					*	*	*
<i>Banksia media</i> R.Br.			*	*	*		*
<i>Banksia speciosa</i> R.Br.		*	*	*	*		*
<i>Conospermum</i> sp.			*	*	*		*
<i>Grevillea macrostylis</i> F. Muell.			*	*	*		*
<i>Grevillea oligantha</i> F. Muell.			*	*	*	*	*
<i>Grevillea oncogyna</i> Diels			*	*	*	*	*
<i>Grevillea pinaster</i> Meisn.	*			*	*	cf.	*
<i>Grevillea sparsiflora</i> F. Muell.		*		*	*	*	*
<i>Hakea cinerea</i> R.Br.			*	*	*		*
<i>Hakea corymbosa</i> R.Br.		*	*	*	*		*
<i>Hakea nitida</i> R.Br.			*	*	*	*	*
<i>Isopogon trilobus</i> R.Br.		*	*	*	*	*	*
<i>Petrophile teretifolia</i> R.Br.		*	*	*	*	*	*
<i>Stirlingia teretifolia</i> Meisn.			*	*	*	*	*
<i>Synaphea</i> cf. <i>polymorpha</i> R.Br.	*				*	*	*
<i>Leptomeria pauciflora</i> R.Br.		*	*	*	*		
<i>Rhagodia preissii</i> Moq.	*		*	*		*	
<i>Gyrostemon brownii</i> S. Moore			*	*	*		
<i>Cassytha melantha</i> R.Br.	*		*	*	*	*	
<i>Billardiera</i> sp.						sp.	
<i>Acacia cochlearis</i> (Labill.) Wendl.	*	*	*	*	*	*	*
<i>Acacia cyclops</i> A. Cunn. ex G. Don.		*	*	*	*	*	*
<i>Acacia erinacea</i> Benth.	*		*	*	*	*	*
<i>Acacia gonophylla</i> Benth.		*	*	*	*	*	*
<i>Acacia nitidula</i> Benth.			*	*	*	cf.	*
<i>Acacia retinodes</i> Schlecht.			*	*	*	*	*
<i>Cassia nemophila</i> Cunn. ex Vog.	*		*	*	*	*	
<i>Daviesia preissii</i> Meisn.	*		*	*	*	*	?
<i>Pultenaea obcordata</i> (R.Br.) Benth.			*	*	*	*	*
<i>Sphaerolobium daviesioides</i> Turcz.		*	*	*	*	*	*
<i>Templetonia retusa</i> (Vent.) R.Br.	*	*	*	*	*	*	*
<i>Boronia crassifolia</i> Benth.		*	*	*	*	*	
<i>Correa reflexa</i> (Labill.) Vent.			*	*	*	*	
<i>Comesperma polygaloides</i> F. Muell.			*	*	*	*	* (granite)
<i>Beyeria leschenaultii</i> (DC.) Baill.	*	*	*	*	*	*	
<i>Dodonaea stenozyga</i> F. Muell.			*	*	*	*	
<i>Stackhousia scoparia</i> Benth.			*	*	*	*	* (granite)
<i>Cryptandra leucophracta</i> Schlecht.	*	*	*	*	*	*	*
<i>Cryptandra tomentosa</i> Lindl.	*		*	*	*	*	*
<i>Pomaderris myrtilloides</i> Fenzl.			*	*	*	*	*
<i>Spyridium denticuliferum</i> Diels		*	*	*	*	*	*
<i>Spyridium spadiceum</i> (Fenzl.) Benth.		*	*	*	*	*	*
<i>Spyridium tridentatum</i> (Steud.) Benth.	*	*	*	*	*	*	*

Species	Western Australia					S. Aust.	Sand Patches			Species confined to siliceous sands
	i	a	d	w	s		PC	TO	TC	
	(see footnote)						(see footnote)			
<i>Alyogyne hakeifolia</i> (Giord.) Alef.	*	*				*	*			
<i>Hibbertia nutans</i> Benth.		*				*			*	?
<i>Hibbertia pungens</i> Benth.		*							*	*
<i>Hibbertia</i> sp.							sp.	sp.		
<i>Pimelea angustifolia</i> R.Br.					*		cf.		*	
<i>Pimelea rosea</i> R.Br.		*	*	*	*		*			*
<i>Pimelea nervosa</i> (Walp.) Meisn.	*	*			*			*		
<i>Pimelea serpyllifolia</i> R.Br.					*	*			*	
<i>Baeckea</i> sp. aff. <i>crispiflora</i> F. Muell.							*			
<i>Beaufortia micrantha</i> Schau.					*		*		*	*
<i>Calytrix tetragona</i> Labill.				*	*	*	cp.	*	*	
<i>Chamelaucium axillare</i> F. Muell.				*	*		*	*		*
<i>Calothamnus gracilis</i> R.Br.				*	*	*		*		*
<i>Darwinia diosmoides</i> (DC.) Benth.	*			*	*	*	*			*
<i>Darwinia vestita</i> (Endl.) Benth.				*	*				*	*
<i>Eucalyptus angulosa</i> Schau. (? = <i>E. incrassata</i>)				*	*		*		*	
<i>Eucalyptus cooperana</i> F. Muell.				*	*		*		*	
<i>Eucalyptus diversifolia</i> Bonpl.					*	*	*	*	*	
<i>Eucalyptus foecunda</i> Schau.					*		*		*	
<i>Eucalyptus eremophila</i> (Diels) Maiden	*			*	*	*	*		*	
<i>Eucalyptus incrassata</i> Labill.				*	*	*		*	*	?
<i>Eucalyptus scyphocalyx</i> (F. Muell.) Maiden & Blakely					*		*		*	
<i>Eucalyptus uncinata</i> Turcz.			*				*		*	
<i>Melaleuca elliptica</i> Labill.	*			*	*		*	*		* (granite)
<i>Melaleuca conferta</i> Benth.				*	*				*	?
<i>Melaleuca lanceolata</i> Otto	*	*		*	*	*	*		*	
<i>Melaleuca pentagona</i> Labill.		*			*		*	*		
<i>Melaleuca pulchella</i> R.Br.				*	*		*	*		*
<i>Verticordia brownii</i> (Desf.) DC.	*			*	*	*	*			?
<i>Verticordia plumosa</i> (Desf.) Druce		*	*	*	*	*	*			?
cf. <i>Acrotriche cordata</i> (Labill.) R.Br.						(*)			*	
<i>Conostephium drummondii</i> (Stschegl.) Gardn.							*		*	(*)
<i>Leucopogon</i> aff. <i>squarrosus</i> Benth.									*	(*)
<i>Lysinema ciliatum</i> R.Br.	*	*	*	*	*	*	*	*	*	*
<i>Styphelia hainesii</i> F. Muell.					*				*	
<i>Samolus repens</i> (Forst.) Pers.	*	*	*	*	*	*	*	*		
<i>Prostanthera</i> sp.							sp.			
<i>Halgania lavandulacea</i> Endl.				*	*	*			*	
<i>Myoporum insulare</i> R.Br.	*	*		*			cf.		*	
<i>Lechenaultia formosa</i> R.Br.	*	*		*	*			*	*	*
<i>Lechenaultia tubiflora</i> R.Br.		*	*	*	*			cf.	*	*
<i>Scaevola crassifolia</i> Labill.	*	*	*	*	*	*	*			
<i>Goodenia affinis</i> De Vriese	*	*		*	*				*	
<i>Goodenia decursiva</i> Fitzg.				*	*		*			* (granite)
<i>Dampiera parviflora</i> R.Br.				*	*		*			?
<i>Stylidium pilosum</i> Labill.				*	*		*			*
<i>Calocephalus brownii</i> (Cass.) F. Muell.	*	*	*	*	*	*		*		
<i>Helichrysum obtusifolium</i> F. Muell. & Sond.				*	*	*			*	
<i>Helipterum floribundum</i> DC.			*	*	*	*			*	
<i>Olearia axillaris</i> (DC.) F. Muell.		*	*	*	*	*	*			

Western Australia:E—Ereman province (Fig. 1); the lower case letters are the initial letter of the zones within the south-west province (Fig. 1) (Beard 1970).

Sand Patch: PC—Point Culver; TO—Toolinna; TC—Twilight Cove (Fig. 2).

sp.—unidentified species present. cf.—specimen collected comparable with species name listed. granite—species associated with granite monadnoeks (Beard 1970).

noted that the Toolinna and Twilight Cove sand patches are very lightly vegetated. This contrasts with the very dense scrub that is found west of Israelite Bay.

Species distributions

Species distributions are given in Table 2. The collections from Point Culver (by M. G. Brooker in 1973) and from Toolinna (by E. C. Nelson in 1973) are both incomplete and include only the most frequent or noticeable species, but the

Twilight Cove collections are much more extensive. This latter area has been visited several times recently while the two former regions have only been visited once. Despite these inadequacies, the information available is considered sufficient to allow comparisons to be made and conclusions to be reached that are unlikely to be altered significantly by further collections.

The species lists (Table 2) were examined and the species restricted to deep siliceous sand were noted. The distributions of the species

within southern Australia were determined using Black 1922, Eichler 1965 and Beard 1970, and data from the Western Australian Herbarium (PERTH). The distributions of some of the species are discussed below.

(a) *Haemodoraceae*

Anigozanthos is endemic to the south-west province of Western Australia, where species are found mainly in the siliceous sand plain (Gardner 1973). *Anigozanthos rufa* is the only species that occurs east of Esperance and was previously recorded as far east as Israelite Bay and Mount Ragged. Brooker (pers. comm.) recorded the species on "burnt sandhills, approx. 5 miles north-west of Point Culver about 3-4 miles from the sea". The species is a typical member of the *quonkan*. It has not been found at Toolinna or Twilight Cove and therefore it is not strictly disjunct on the sand patches.

(b) *Proteaceae*

Both *Banksia* and *Adenanthos* are found in the siliceous sand plain areas west of Israelite Bay, and as far as Shark Bay. The genera are mainly restricted to areas where the soils have little or no calcium, and no species of either genus has been recorded on the Nullarbor Plain in calcareous soils. Neither genus is endemic to Western Australia but none of the species found in south-western Australia occur in south-eastern Australia (Rao 1971).

Banksia speciosa is a very common shrub near Israelite Bay and at Mount Ragged. It was collected by Brooker at Point Culver, thus extending its distribution further to the east. It probably occurs in abundance along the Israelite Plain, but does not reach Toolinna. *Banksia media* was collected at Toolinna and also at Point Culver, but it has never been found at Twilight Cove. Therefore the Toolinna population is the most easterly population of a Western Australian *Banksia* species. *B. media* is common in the *quonkan* between Israelite Bay and Cape Riche (Erickson *et al.*, 1973), and of mallee scrub further inland (J. S. Beard, pers. comm.).

John Eyre stated in his journal for May 1, 1841:

One circumstance in our route today cheered me greatly, and led me to expect some important and decisive change in the character and formation of the country. It was the appearance for the first time of the *Banksia*, a shrub which I have never found to the westward of Spencer's Gulf [South Australia], but which I knew to abound in the vicinity of King George's Sound [Western Australia], and that description of country generally Isolated as it was amidst the scrub and insignificant as the stunted specimens were that I first met with, they led to an inference that I could not be mistaken in . . . " (Eyre 1847, vol. 2, p. 13-14).

That night (May 1) Eyre probably camped near the Toolinna waterhole (Fig. 2), having already passed through sand patch which is situated northeast of the waterhole. The description of the "stunted specimens" of *Banksia*, fits the habit and form of the plants of *B. media* that were seen recently by the author at Toolinna.

On the succeeding day, Eyre was travelling through the Point Culver sand dunes and he later wrote:

"We moved through a country which gradually became more scrubby, hilly and sandy The smaller *Banksia* [*B. media*] now abounded whilst *Banksia grandis*, and many other shrubs common at King George's Sound, were frequently met with." (Eyre 1847, vol. 2, p. 14)

The observation that the country became more sandy is exactly what would be expected in that region; the limestone areas giving way to the dune systems. The increasing prevalence of Western Australian plant species coincides with the situation at Point Culver. Eyre's reference to *Banksia grandis* is incorrect as that species is not commonly found east of King George Sound; the species encountered must have been *B. speciosa*. The most easterly sighting of *Banksia media* is marked on the map published with Eyre's narrative though the position is somewhat inaccurate (Eyre 1847).

Adenanthos species are not as conspicuous as *Banksia*, but they form an important component of the *quonkan* vegetation west of Israelite Bay. *A. cuneata* has been collected at Israelite Bay, Twilight Cove and Mount Ragged (Nelson, in press) and most recently at Toolinna. Brooks collected the species in the late nineteenth century at Israelite Bay, and Batt and Carey collected it at Twilight Cove in 1889 (MEL). The species is abundant at Israelite Bay, but at Toolinna and Twilight Cove it is very rare. Brooker did not collect the species at Point Culver. It is probable that it occurs there today, but it may be rare.

Adenanthos forrestii was first collected by John Forrest (Mueller 1882) on his survey in 1870. Two specimens from his journey are extant (MEL); one is labelled "near Point Culver 33° 14' S., 124° 2' E." This location is named 'Wattle Camp' on standard topographic maps and is described by Brooks (1894) as an area of dunes consisting of "very fine sand that has a yellow tint". The second specimen came from the Twilight Cove area. Thus the species was only known from these two areas before its recent collection at Toolinna. It has not been collected at Point Culver, but it could occur there. Forrest's location "near Point Culver" has been misinterpreted in the past and should be regarded now as referring to Wattle Camp, about 36 km south of Point Culver. The species is endemic to these sand patches, and to the Israelite Plain; it is not recorded elsewhere.

A third species of *Adenanthos** was collected at Toolinna in October 1973. It is apparently endemic to that sand patch. It could not be found at Twilight Cove, and no species of *Adenanthos* were collected at Point Culver by Brooker. The possibility that it occurs in these latter areas cannot be ruled out.

* This species has not yet been described. A description is to be published soon by E. C. Nelson in a taxonomic revision of *Adenanthos*.

Among the other members of the family, *Isopogon trilobus* and *Petrophile teretifolia* have been collected at Point Culver, and the former was recently found at Twilight Cove also. Neither species has been collected at Toolinna. *Synaphea cf. polymorpha* was collected at Toolinna and at Twilight Cove. Several species of *Hakea*, including *H. corymbosa* and *H. nitida* were collected at Toolinna and at Point Culver. A number of *Grevillea* species grow at Point Culver, but they have not been recorded on the more easterly sand patches. Most of these species are found in the Israelite Bay and Mount Ragged areas, and like the species of *Adenanthos* and *Banksia* they are restricted to non-calcareous soils. None of these Proteaceae is found on the dunes near the beach at Twilight Cove which contain small amounts of calcium carbonate. The flora of the dunes near the sea, that have some calcium carbonate incorporated, is very different and consists mostly of littoral plants, with occasional *Eucalyptus* and *Melaleuca* species.

(c) Myrtaceae

Apart from some significant species of *Eucalyptus* that Parsons (1970) has already discussed, the most significant members of the family that have been recorded on these siliceous dunes are *Chamelaucium axillare*, *Darwinia vestita* and *D. diosmoides*, *Calothamnus gracilis*, *Verticordia brownii* and *V. plumosa*.

Chamelaucium axillare occurs in the *quonkan* between Esperance and Israelite Bay. It has not been collected east of Toolinna, where it was found recently. The genus is endemic to south-western Australia, and is restricted to sand plain areas in that region. *Calothamnus gracilis* is listed by Beard (1970) as occurring in the Ereman Province, but it is usually a sand-plain species (Erickson *et al.* 1973). *Darwinia* and *Verticordia* species fall into similar categories. They are calcifuge species, and while the genera are found in South Australia these species are south-western endemics (Black 1922, Eichler 1965, Beard 1970).

(d) Goodeniaceae

Lechnautilia species are frequent in the *quonkan* west of Mount Ragged. *L. formosa* and *L. tubiflora* have been collected as far east as Twilight Cove, but they are both infrequent on the sand patches. These species are very common near Israelite Bay and are endemic to Western Australia. Some other members of the family recorded on or near the sand patch are calcicoles such as *Scaevola crassifolia* (Parson 1970, N. M. Wace, pers. comm.).

(e) Other families

Other genera recorded on the sand patches but not in the surrounding limestone country include *Pimelea*, *Comesperma* and *Stylidium*. Several different species of *Pimelea* have been

recorded on the sand patches, and representatives of the genus are frequent on the younger, coastal sand dunes near Israelite Bay, particularly *Pimelea ferruginea*. *Stylidium pilosum* was collected by Brooker at Point Culver, and it is known from the area between Esperance and Israelite Bay. *Comesperma polygaloides* was collected at Twilight Cove as was *Stackhousia scoparia*; both species found west of Mount Ragged in siliceous sand associated with granite monadnocks (Beard 1970).

The species listed in Table 2 that are restricted to siliceous sand habitats are all endemic to Western Australia. The species that are found either exclusively on limestone or on both siliceous sand and calcareous soils usually occur in south-eastern Australia and in south-western Australia. Thus the flora of these sand patches is composed mainly of Western Australian calcifuge species.

Some of the species had not previously been noted in areas east of Israelite Bay and most of them are absent from the limestone plateau of the Nullarbor Plain. The total species numbers in the sand-patches north-east of Point Culver are very low compared with similar areas west of Israelite Bay; the flora of the sand patches is therefore a depauperate form of the *quonkan* flora typical of the Esperance-Israelite Bay region. However the presence of some of the species at Point Culver indicates that many of the plants may be found on the Israelite Plain, but due to the lack of collections from that area they were not recorded east of Israelite Bay. The flora of the Eyre zone can be said to extend as far as Point Culver, and not to end abruptly at Israelite Bay. It is interesting to note that certain birds which occur in south-western Australia but which previously had not been recorded north-east of Israelite Bay, have recently been seen in the sand-dune at Point Culver, Toolinna and Twilight Cove (See Appendix 1).

There is a gap of about 25 km between Toolinna sand patch and the major dune system at Point Culver. The Point Culver cliff-top dunes are linked to the Israelite Plains by ramps of sand built up by wind against the Wylie Scarp. Similarly between the Toolinna dunes and the second major system at Twilight Cove there is a gap of about 85 km, which is devoid of deposits of siliceous sand apart from the very small sand patch south-west of Point Dover. The areas between the sand dunes are either bare exposed limestone or have clay soils derived from limestone. These intervening areas present no suitable habitats for calcifuge species.

Discussion

These isolated siliceous dune systems are colonised by species which are endemic to Western Australia, and which are considered to be intolerant of soils containing high proportions of calcium. The sand patches are surrounded by an environment which these species are unable to colonise due to the presence of limestone. The

climate, inland from the coast, is apparently unsuitable for the growth of many of these plants; it is characterised by high summer temperatures and low intermittent rainfall.

There are several hypotheses that can be advanced to explain the presence of these species on the sand patches. Firstly, long range dispersal can be considered; plants may have been transported from the areas to the west over the intervening unsuitable habitats by an agency such as wind or animals. Secondly, migration from the west could have occurred when the conditions, both climatic and geomorphic, were suitable in the past. Finally the species could have had a continuous distribution along the coast, but this has since been fragmented (Parsons 1970).

Long range dispersal of plants has been discussed many times. A propagule can probably be dispersed over long distances even if it is not apparently adapted for dispersal by a specific agency such as sea currents, wind or birds (Good 1947). However long range dispersal is only successful if the propagule reaches a habitat that is suitable for its germination and the survival and subsequent reproduction of the plant (Rao 1971). The species that are found on the dune systems east of Point Culver are not obviously adapted for long range dispersal. *Adenanthos* fruits do not appear to be adapted in any way for dispersal over long distances. It is usually difficult to find seeds of *Adenanthos* more than a few metres from a parent plant as the propagules tend to drop directly to the ground on maturity. *Banksia* species also are not adapted for long range dispersal and the same probably applies to the other genera of the Proteaceae and other families. Rao (1971) argued against ocean dispersal of the Proteaceae as the propagules have flimsy coats and are thus susceptible to toxic effects of sea water. Similarly bird dispersal is more probable if species have drupaceous fruits, which none of the species considered here possess (Rao 1971).

It should be noted that many of these species do not have seeds which will germinate readily. In the *quonkan* seedlings of *Adenanthos* species are very rarely found in areas where there are mature plants established. Very occasionally seedlings are encountered in disturbed ground but only if a major disturbance has occurred, such as "bulldozing" or clearing. Seedlings will be found immediately after a fire has burnt the vegetation in an area. This applies equally to other members of the Proteaceae; *Banksia* seeds are usually not released from the fruiting cones until after a fire (Gardner 1959) and they fall directly to the ground. It is unusual to find seedlings among mature communities of *quonkan* vegetation; all plants are apparently of the same age as they probably all germinated after the last fire in the area. In the Proteaceae microbial stimulation may be necessary, as seeds will not readily germinate in sterile soils (Rao 1971, Vogts 1960). When these characteristics are considered, along with the lack of adaptation to dispersal over long distances, long range

dispersal must be discounted. The extreme sensitivity of many south-western Australian species to changes in edaphic conditions (Diels 1906, Speck 1958) and the very restricted distribution ranges of some species argues strongly in favour of this lack of dispersal capacity.

The second and third hypotheses differ only in their starting points. Parsons (1970) has suggested that disjunctions in the distributions of *Eucalyptus* species can be accounted for simply by postulating a continuous strip of siliceous sand linking the Roe Plains and the areas to the west, during the Quaternary low sea levels. "This would provide continuous species distributions which were subsequently fragmented by rising sea levels" (Parsons 1970).

In assessing this idea it is important to remember that it seems that the species concerned cannot migrate rapidly even over short distances. Thus while there certainly would have been vegetation cover on the exposed coastal lowlands between the Israelite Plains and Twilight Cove, that vegetation is unlikely to have contained all the species typical of the *quonkan*. Rather, only a small proportion of the *quonkan* species may have colonised that coastal area, due to differential migration rates and climatic and edaphic barriers.

In this context it is significant that certain species are not recorded at Twilight Cove, but have been collected in areas to the south-west. A similar situation relates to the Toolinna sand patch. Thus *Banksia speciosa* and *Anigozanthos rufa* are recorded only as far east as Point Culver; they could have reached that dune system by migrating along the existing Israelite Plain. *Banksia media* and *Chamelaucium axillare* are found at Toolinna but not at Twilight Cove. Despite the incomplete collections it is noticeable that the floras of each sand patch becomes poorer in species typical of the *quonkan* the further east they are situated. The Point Culver flora is not as rich in genera and species as that of the Israelite Bay area, and the Toolinna flora is depauperate compared with the Point Culver flora.

This suggests that these species have different capacities to migrate, or if they migrate at the same rate that some species have become extinct from the more easterly dune systems. The latter hypothesis is probably partly correct; due to changes in climate some species may have failed to survive. However, both Frank (1971) and Martin (1973) have indicated that there have not been substantial climatic changes during the late Quaternary in this area. While changes have occurred that have caused vegetation patterns to alter, the climate in the late Pleistocene and Holocene was not very much drier, or wetter, than the climate of the present time (Martin 1973). Thus the climatic effects on the vegetation of these sand dunes may have been small. If different rates of migration are involved, those species that could migrate relatively rapidly reached Twilight Cove, while

those that were slower moving along the exposed coastal plain only reached Toolinna, during the period when sea levels were low.

When marine transgression occurred any plants that had reached Twilight Cove were isolated there and those which were at Toolinna became separated from plants on the other dune system. As mentioned above, the cliff-top dunes were probably emplaced by wind-built ramps situated against the cliffs. The plants would have moved from the exposed coastal plain up these ramps on to the dune systems. Marine erosion has removed these basal ramps, since the sea levels returned to the present datum.

The absence of endemic species on the sand patches, with the probable exception of species of *Synaphea* and *Adenanthos*, indicates that there has been insufficient time for speciation to occur in these isolated populations. The forms of the species that are found on the sand patches are not perceptibly different from phenotypes at Israelite Bay or Mount Ragged. Thus it is probable that the populations at Twilight Cove and Toolinna have only been isolated since the last glacial maximum, and possibly only since the sea levels reached the base of the Baxter Cliffs between 10 000 and 6 000 years B.P. Thom and Chappell 1975; Jennings 1971). It is possible that species which are not potentially very variable, could have been in these areas for longer periods, if the dunes are older than Holocene or late Pleistocene. In the case of *Adenanthos*, the genus is morphologically variable and shows a very substantial amount of phenotypic plasticity, yet forms of the species found on these dunes do not differ significantly from forms found in other areas where those species occur.

It is possible to conclude that the present cliff-top dune systems were probably emplaced in the Holocene, or late Pleistocene, and that the species distribution patterns found in this area have resulted from migrations along a coastal plain during the last period of low sea levels. Subsequent return of sea level to present datum fragmented distributions and isolated species on dune systems disjunct from their main areas of occurrence. Long range dispersal is not thought to account for these disjunctions due to the peculiar propensities of the south-western Australian flora and to the lack of adaptations of their propagules to dispersal over long distances.

One feature of southern Australian phyto-geography is the marked difference between the floras of south-eastern and south-western Australia. Several workers have discussed this situation and concluded that species similarities can be accounted for by migrations in post-Tertiary times (Burbidge 1960, Green 1965, Marchant 1973). The Nullarbor Plain limestone plateau is considered to present an edaphic barrier to east-west migrations due to the apparent calcifuge propensity of the Australian vegetation (Crocker and Wood 1947). The flora of south-western Australia exhibits a very high rate of endemism

at species level (Beard 1969) and only a very few species that are intolerant of lime-rich environments are found on both sides of the Great Australian Bight.

That only western calcifuge species have reached Twilight Cove is important. Those species that are found both in South Australia and at Twilight Cove (Table 2) are not typically restricted to siliceous sand plain; an example of this category of species is *Eucalyptus diversifolia* (Parsons 1969). It would be expected that an exposed lowland plain, south of the Nullarbor Plain on the continental shelf, would permit migration in *either* direction; to the west or to the east. The absence of eastern calcifuge species demonstrates that either time was not sufficient for such a migration from the east to occur, or that there was a barrier either edaphic or climatic. Migration of these species requires that the exposed plain be composed of siliceous sands. Lowry (1970) noted that between Israelite Bay and Eucla (Fig. 1), the percentage of calcium carbonate in beach sand increased from 5 per cent in the west to about 50 per cent in the east. This may have been the situation in the past, and the higher calcium carbonate levels in eastern areas would have produced an edaphic barrier (Parsons 1970). Further, if calcifuge species were to migrate from the east leaching of the calcareous sands in the east would have to have taken place. A very long time could elapse before a non-calcareous substrate was available for colonisation and migration. One small area of calcareous sand would constitute a very effective barrier to migration. Such a situation would not have prevented calcicole species from migrating from east to west, or *vice versa*, as noted by Parsons (1969). While the prevailing direction of dispersing agencies such as winds and currents, are towards the east, they probably would have had little effect on species migrations unless the species were dispersed by these agencies. As indicated above this is considered unlikely. With only small climatic changes during the Pleistocene period it would appear unlikely that there was a climatic barrier.

The evidence presented here suggests that the duration of periods suitable for migration in the Late Quaternary, or at least during the existence of the extant cliff-top dunes, was insufficient for calcifuge species to migrate across the Great Australian Bight in either direction. Species similarities between the south-eastern and south-western regions of Australia among groups of taxa that have similar propensities to those discussed here, may have resulted from migrations across the exposed continental shelf during the Quaternary. Long range dispersal does not provide a reasonable alternative. If the species disjunctions noted on these cliff-top dunes have resulted from migrations during marine regression in the late Pleistocene, a suitable period for east-west interchange must pre-date the last period of low sea-levels (120 000-6 000 years B.P.; Chappell 1974).

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Appendix 1: Distribution of birds on south-western Nullarbor Plain

Reilly, Brooker and Johnstone (in press) have recorded the occurrence of species of birds along the coast of the Great Australian Bight, between Point Culver and Twilight Cove. Nine honeyeaters (*Meliphagidae*) were noted, of which two (*Phylidonyris novaehollandiae*—New Holland honeyeater; *Gliciphila melanops*—tawny-crowned honeyeater) were recorded east of their previously known limits of distribution in Western Australia. These two species are

members of the Bassian avifauna of southwestern Australia, and were observed only in the vegetation on the siliceous sand deposits. They are probably dependent for food on plants that copiously produce nectar and which are also restricted to those areas, such as species of *Adenanthos*, *Banksia*, *Grevillea* and *Anigozanthos* (Reilly *et al.* in press).

Adenanthos spp., *Anigozanthos rufa*, *Grevillea* spp., and certain other plants are pollinated by nectar-seeking birds. As these plants are found in soils with a very low calcium carbonate content, they probably do not occur east of Twilight Cove and on the limestone areas due to the increased proportions of calcium carbon-

ate in the soils and sand. Survival of populations of these species requires the presence of suitable pollinators. The presence of the honeyeaters in the sand patch vegetation is presumably important with respect to the survival of these disjunct species populations.

The absence of certain honeyeaters from the areas east of Twilight Cove and from limestone areas (Reilly *et al.* in press) may be due to the absence of populations of nectar-producing plants on which those honeyeaters may be dependent.

Reference: Reilly, P. N., Brooker, N. G., Johnstone, G. W., (in press): Birds of the southwestern Nullarbor Plain: *Emu*.

15.—The development of premolar and molar crowns of *Antechinus flavipes* (Marsupialia, Dasyuridae) and the significance of cusp ontogeny in mammalian teeth

by M. Archer¹

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Abstract

A series of fourteen transversely sectioned juvenile *Antechinus flavipes* was studied to reveal information about the ontogenetic development of the cheek-teeth. Only three premolar tooth family positions were found. There was no evidence for milk-teeth posterior to the canine. In the upper molars, the first cusp to initiate and calcify was the metacone, followed by the paracone. Styler cusp D developed and calcified before styler cusp B. In the lower molars, the protoconid developed and calcified first. The metaconid was generally second. In the M_1 the hypoconid developed and calcified before the paraconid. Reasons are given for believing that ontogeny of tooth cusps does not necessarily indicate phylogeny, and that ontogeny may be at least partly dependent on the size of the cusps of the adult crown.

Introduction

The order in which the cusps develop in molar teeth of mammalia is generally regarded as an indication of the identity of the cusps and in particular of the identity of the paracone and the protoconid. In recent years B. K. B. Berkovitz has shown that in some marsupials (e.g. *Didelphis* and *Setonix*) there must be some doubt as to the general applicability of using ontogeny in this manner.

Here, a study of the developing cusps of the cheek-teeth of *Antechinus flavipes* is made in order to discover the situation in an Australian marsupial which has a structurally primitive dentition.

A series of heads of fourteen juvenile *Antechinus flavipes* of known ages were sectioned transversely. The preparation of specimens used in this study is described by Archer (1974). The sixteen developmental stages examined ranged from the 4 Day Stage (i.e. 4 days postbirth) to the 105 Day Stage and included a 4 Day, 10 Day, 12 Day, 15 Day, "22" Day (actually developmentally younger than the next stage), 21 Day, 28 Day, 32 Day, 36 Day, 40 Day, 44 Day, 51 Day, 59 Day, 60+ Day, 83 Day, and 105 Day Stage. The 83 Day Stage and the 105 Day Stage animals were gross skeletal preparations and are registered in the Western Australian Museum mammal collections as M 8091 and M 8092 respectively.

Cheek-tooth nomenclature follows that of Thomas (1888) bearing in mind that Archer (1974) has established that dP4 is not a milk-tooth and is the first of the dP4-M4 *Zahnreihe*. Basic cusp nomenclature is that used by Benley (1903) and Simpson (1936), with modifications (Fig. 1) as presented in Archer (1975).

Results

The canine

The upper canine was slightly more advanced in development in any given stage than the lower canine. Enamel knots (Fig. 2) were present in both teeth in the position of the future paracone and protoconid of both crowns. The canines, unlike any of the other cheek-teeth, both had rudimentary uncalcified milk predecessors which were resorbed soon after development.

P1

From its initiation P₁ was in advance of P¹ in development; it also calcified one stage earlier. Both teeth however, were in the same state of development in later stages and in the 60+ Day Stage both had well-formed roots and were nearing eruption. Enamel knots were not observed.

P3

The P₃ was advanced in development over P³ in all stages observed, although calcification began at approximately the same time in the 40 Day Stage. Enamel knots were not observed.

P4

The P₄ and P⁴ developed at about the same time, in the 40 Day Stage. Development was very late and calcification was not observed in the sectioned material.

dP4

DP₄ initiation had begun by the 4 Day Stage. DP⁴ was slower in development, initiation occurring in the 10 Day Stage. In later stages however the dP⁴ was advanced in development over the dP₄. An enamel knot was observed in both teeth above the area of the presumptive paracone and protoconid, the only cusps that developed on the crowns of these teeth (Fig. 3).

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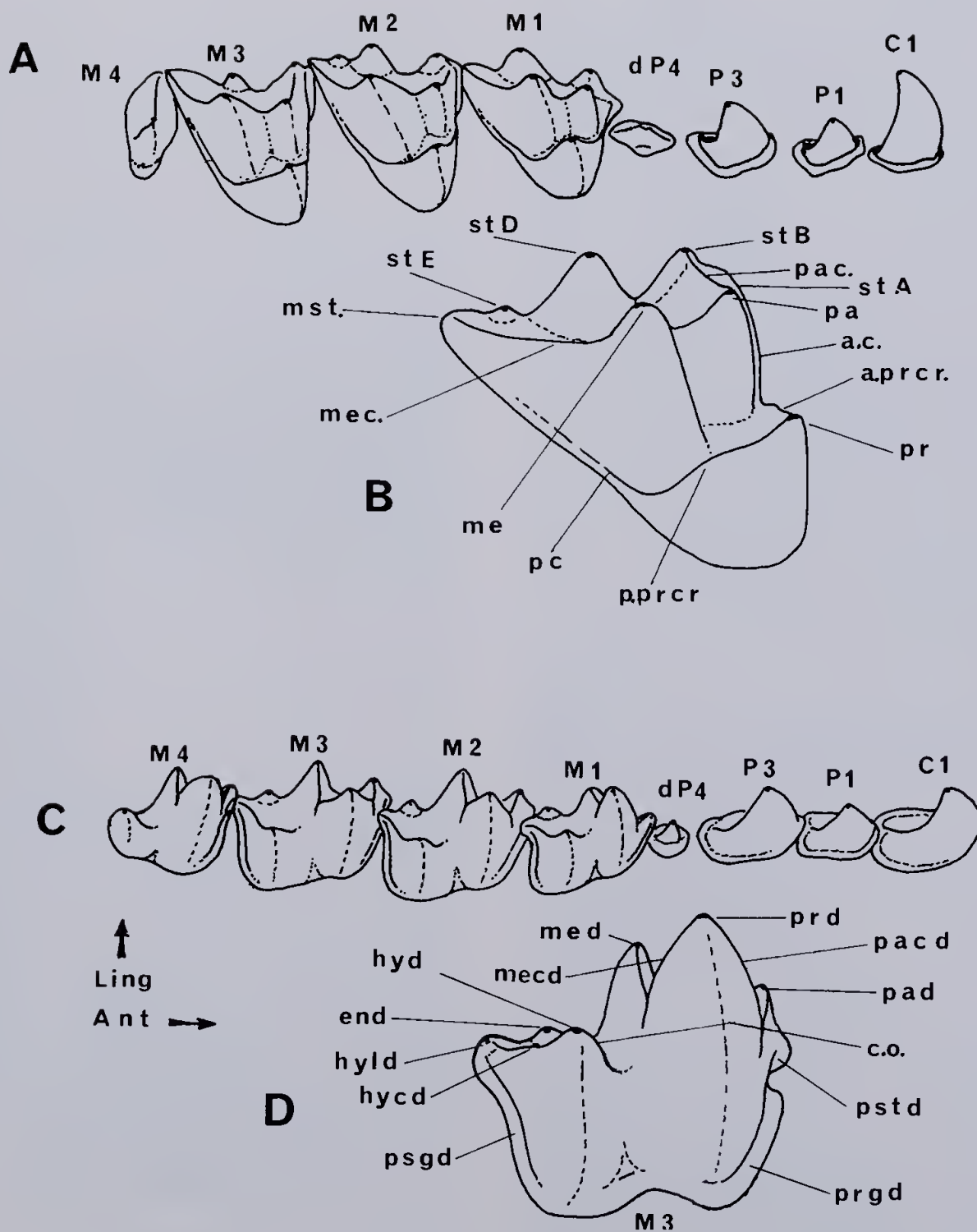


Figure 1.—The morphology of the cheek-teeth. 1A. RC_1-M_1 . 1B. RM_2 . 1C. RC_1-M_1 . 1D. RM_3 . Abbreviations: a.c., anterior cingulum; a. prcr., anterior protocrista; c.o., crista obliqua; end, entoconid; hycd, hypocristid; hyd, hypoconid; hyld, hypoconulid; me., metacone; mec., metacrista; mecd, metacristid; med, metaconid; mst., metastylar corner of tooth; pa., paracone; pac., paracrista; pacd, paracristid; pad, paraconid; p.c., posterior cingulum; p.prcr., postprotocrista; pr., protocone; prd., protoconid; prgd, precingulid or anterior cingulum; psgd, postcingulid or posterior cingulum; pstd, parastylid; stA, stylar cusp A; stB, stylar cusp B; stD, stylar cusp D; stE, stylar cusp E.

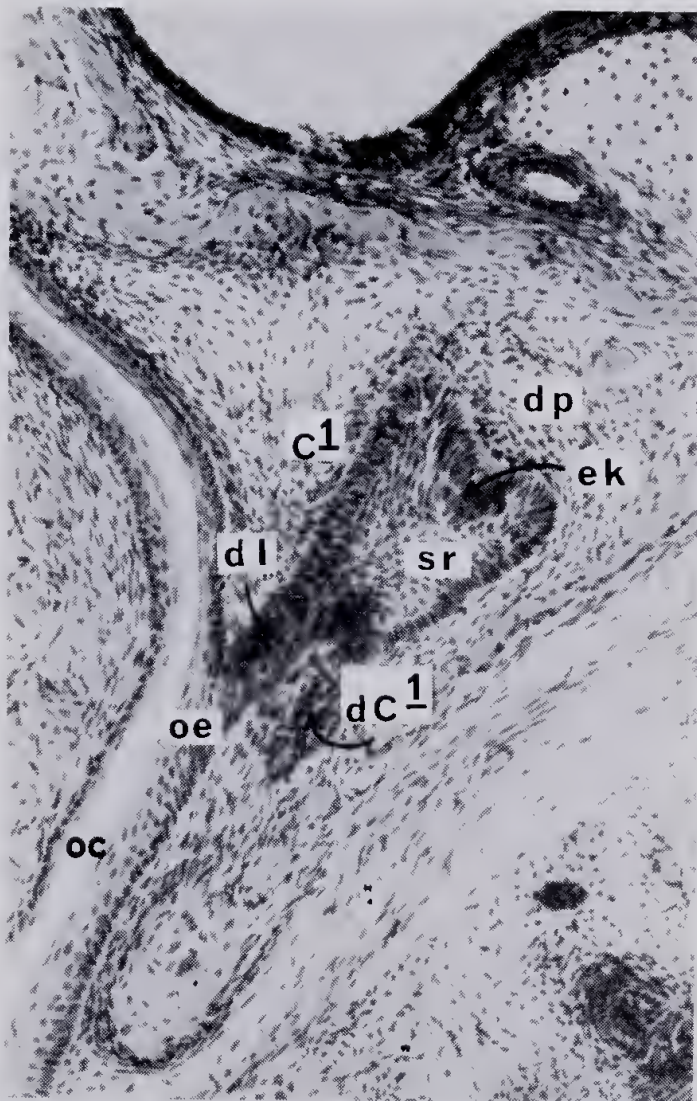


Figure 2.—The upper canine at the 15 Day Stage. Abbreviations; C¹, upper canine; dC¹, rudiment of deciduous canine tooth germ; oe, oral epithelium; dl, dental lamina; sr, stellate reticulum; dp, dental papilla; ek, enamel knot; oc, oral cavity; e, enamel; d dentine x 150.

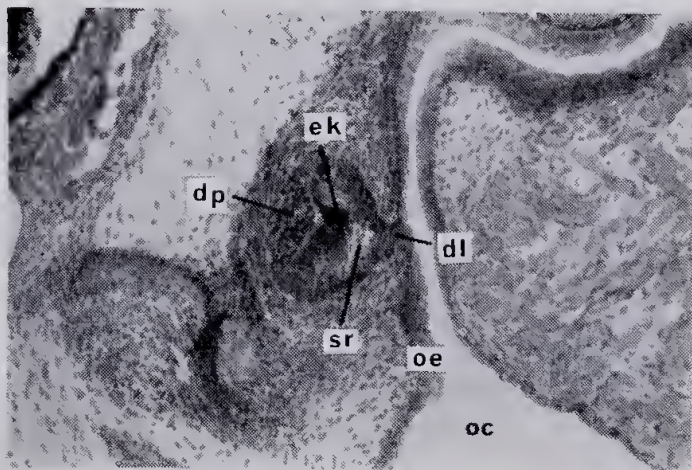


Figure 3.—The upper milk premolar at the 10 Day Stage. Abbreviations as in Fig. 2. x 150.

There were problematical structures associated with the dP⁴ and dP₄ in the 60+ Day Stage animal (Fig. 4). These were concentrically laminated epithelial structures developed in the oral epithelium and the enamel epithelium (which at this stage consisted of the inner and outer enamel epithelial layers pressed together) at the tips of the nearly erupting dP₄. A similar but smaller structure was observed above the lingual cingulum of the dP⁴. These structures may be Pearls of Serres (see Scott & Symons 1961). The dental lamina had completely degenerated from the region of the dP₄ in previous stages. These Pearls of Serres were not observed in association with any other teeth but very few teeth were examined at this relatively late stage of development.

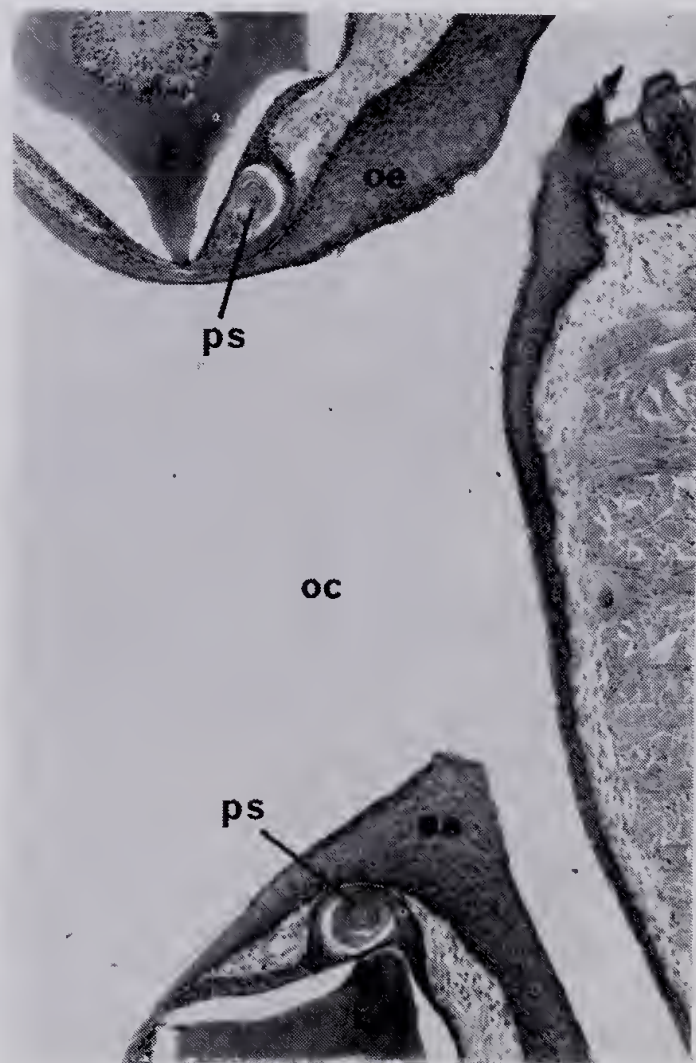


Figure 4.—The upper and lower milk premolar at the 60 + Day Stage. ps, tissues resembling Pearls of Serres. Other abbreviations as in Fig. 2 x 75.

M₁

M₁ development preceded that of M¹. The first three cusps visible in the 32 Day Stage in M¹ were the metacone, stylar cusp D and the paracone. The metacone was the largest and had begun calcification. Calcification may have just begun at the tip of the paracone in this

stage, but clearly had not proceeded as far as it had on the metacone. In the 36 Day Stage stylar cusp D was large but had not begun calcification and the protocone was only beginning to form.

The paracone had clearly become calcified. In the 40 Day Stage stylar cusp D was just beginning calcification (Fig. 5). Stylar cusp B was developed but not calcified. In the 44 Day Stage the protocone was undergoing calcification (Fig. 6). Stylar cusps B and A did not undergo calcification until the 51 Day Stage.

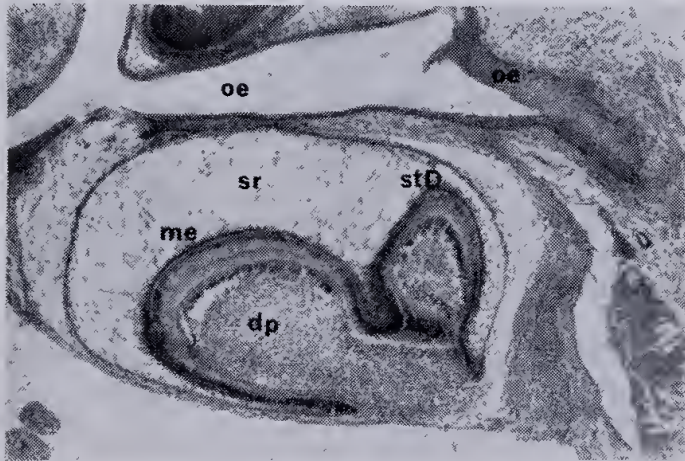


Figure 5.—The upper first molar, section through the metacone and stylar cusp D, at the 40 Day Stage. Both cusps are undergoing calcification. At this stage only the metacone, stylar cusp D and the paracone were calcified. *me*, metacone; *stD*, stylar cusp D. Other abbreviations as in Fig. 2 x 75.

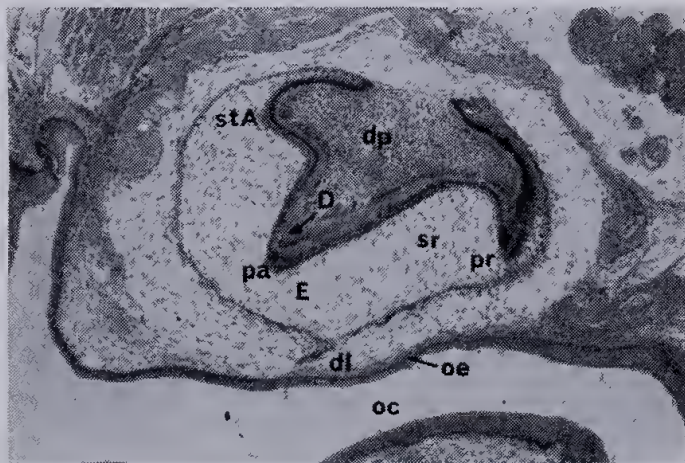


Figure 6.—The upper first molar, section through the protocone, paracone and stylar cusp A at the 44 Day Stage. Only the paracone is shown calcified but the beginning calcification of the protocone is apparent in sections posterior to the section shown. At this stage the metacone and stylar cusp D are also calcified. *pr*, protocone; *pa*, paracone; *stA*, stylar cusp A. Other abbreviations as in Fig. 2. x 75.

In M^1 the protoconid was the first cusp to become visible in the 15 Day Stage as well as to calcify in the 21 Day Stage. The hypoconid and metaconid were distinguishable but uncalcified in the 36 Day Stage. All of these cusps had begun calcification by the 40 Day Stage but the hypoconid was the least developed. The

entoconid may have been distinguishable in the 44 Day Stage. By the 51 Day Stage the paraconid had begun calcification. The entoconid and hypoconulid may have just begun calcification.

M2

In M^2 the metacone was distinguishable in the 40 Day Stage. By the 44 Day Stage the paracone, protocone, stylar cusp D and possibly stylar cusp B had also appeared but only the metacone had clearly become calcified (Fig. 7a). The paracone may have just begun calcification (Fig. 7b). The paracone had clearly begun calcification by the 51 Day Stage and all major cusps had become calcified by the 59 Day Stage.

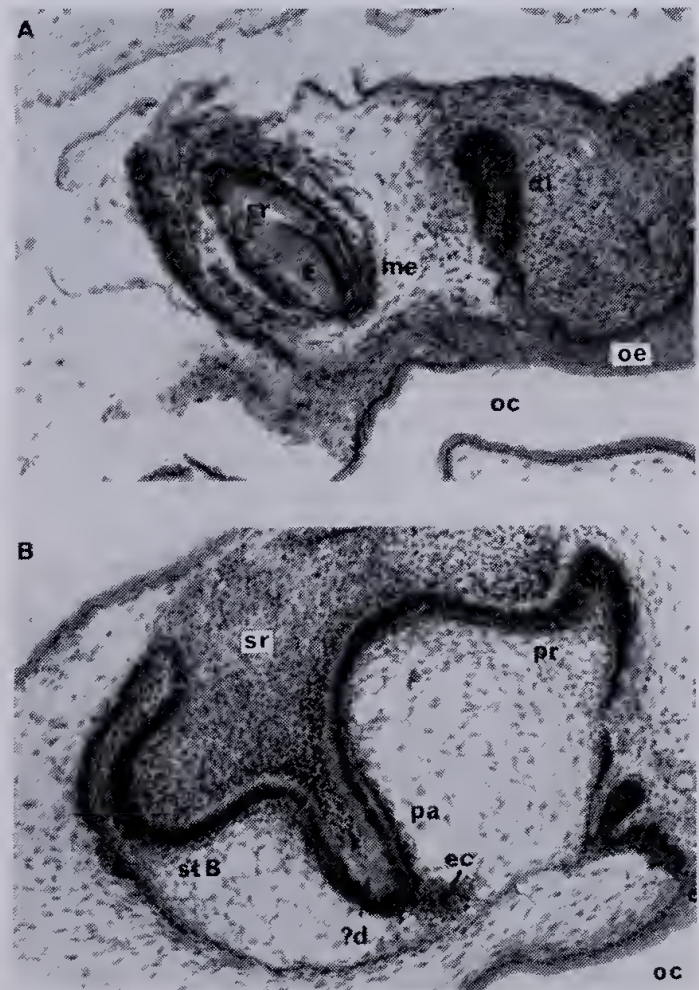


Figure 7.—The upper second molar at the 44 Day Stage. 7A. Section through the well-calcified metacone showing enamel as well as dentine, and the posteriorly extended dental lamina. 7B. Section through the protocone, paracone and stylar cusp B showing the slight (if any) calcification of the paracone. There appears to be an enamel cord above the paracone tip. *ec*, enamel cord. Other abbreviations as in Figs. 2, 5 and 6. x 150.

In M_2 in the 36 Day Stage, the protoconid, metaconid, paraconid and possibly the hypoconid were present but only the protoconid had begun calcification. In the next stage the metaconid had calcified. The entoconid appears to be distinguishable by the 44 Day Stage. The paraconid did not begin calcification until the 51 Day Stage. The entoconid was calcified by the 59 Day Stage.

M3

The metacone of M³ was first distinguishable in the 59 Day Stage. It was uncalcified. An enamel cord was observed over the tip of the cusp (Fig. 8). By the 60+ Day Stage, the paracone, metacone and protocone were distinct but only the first two had undergone calcification.

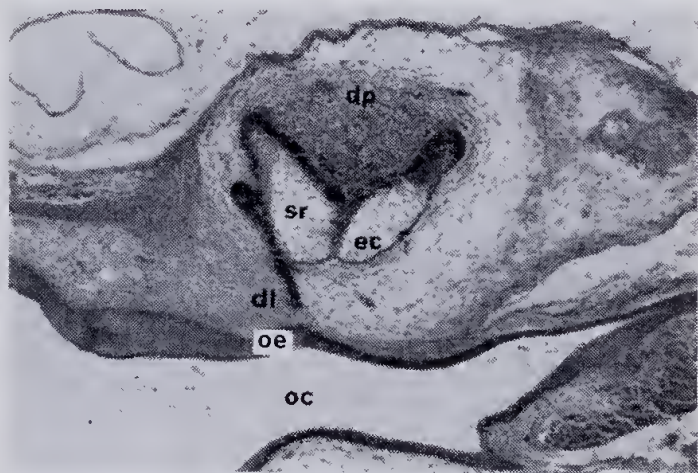


Figure 8.—The upper third molar at the 59 Day Stage showing an enamel cord over the tip of the metacone. Abbreviations as in Fig. 7. x 75.

In M₃ the metaconid and protoconid were present in the 44 Day Stage but only the latter was calcified. The paraconid was distinguishable in the following stage. By the 59 Day Stage all cusps were present and all were calcified except the entoconid and hypoconulid. By the 60+ Day Stage the hypoconulid had begun calcification.

M4

The M⁴ in the 60+ Day Stage was merely a swelling of the dental lamina. The M₄ on the other hand had all three trigonid cusps formed and calcified in the 60+ Day Stage.

Table 1 summarizes the data presented above.

Discussion

Cusp formation and homology

In 1874 Cope proposed that the complex therian molar had developed through addition of cusps peripheral to a single cusp of a primitive tooth. This basic premise was in contrast to that of others such as Bolk (1922) in which the therian molar was seen as a result of fusion of adjacent single-cusped primitive teeth. Cope's premise has generally been accepted (e.g. see Gregory 1934, Butler 1941, Crompton 1971). However, there has been disagreement about which cusp on the therian molar is the primitive cusp. Osborn (1888) believes it is the lingual cusp or protocone of the upper molar and the antero-buccal cusp or protoconid of the lower molar. This view has been accepted by many later authors (e.g. Gregory 1934, Simpson 1936).

Winge (1941) however believes that the variably present external styler cusps of the upper molars and the three lingual cusps, the paraconid, metaconid and entoconid of the lower molars are the oldest cusps and therefore the central styler cusp and the metaconid represent the ancestral primitive cusps. Gidley (1906) suggests that the paracone of the upper molars and the protoconid of the lower molars were the first ancestral cusps. Gregory's view has been supported by Wortman (1902) and Butler (1937) who argue that on the basis of observations of upper premolars that when these teeth become progressively molarized posteriorly along the tooth row through evolution, they often produce secondary cusps serially homologous with the protocone and metacone, suggesting that the ancestral cusp is the paracone in upper molars as well as premolars. Embryological evidence of Röse (1892a), Tacker (1892), Woodward (1896), Kupfer (1935), Marshall & Butler (1966), and Berkovitz (1968) indicates that in marsupials and eutherians the paracone and protoconid develop first ontogenetically and Butler (1956) concludes that this supports the view that these cusps are the ancestral molar cusps. However, Röse (1892b) and Berkovitz (1967a) have observed that in some molariform marsupial teeth examined, the metacone developed first.

The results of Röse (1892b) and Berkovitz (1967a) appear to cast doubt on the concept that position in the ontogenetic sequence of cusp development can indicate the primary cusps. It is also possible, but not likely, that the cusp called a metacone in these marsupials is homologous with the paracone of other marsupials (e.g. *Trichosurus* and *Setonix*) and mammals in general. It is also possible, as Butler (1956) suggests, that Röse (1892b) may not have used the same criteria as other authors to establish the state of development of a cusp but this is not likely because Berkovitz (1967a) has confirmed Röse's (1892b) observations in a specimen of the same genus (*Didelphis*).

Upper molars

In the M¹⁻² of *Antechinus flavipes* examined in the present study it is apparent that the metacone precedes all the other cusps in development and calcification. This may also be the situation in M³⁻⁴. The paracone is the next cusp to form and calcify, followed by the protocone. This developmental sequence is unlike any other reported except for that of *Didelphis* (Röse 1892b, Berkovitz 1967a). It also appears to contrast with the findings of Woodward (1896) who after examining one specimen of *Antechinus* sp. states (p. 284) that "The paracone above and the protoconid below develop before any of the other molar cusps". However, some doubt about Woodward's conclusion must stem from the fact that he examined only one specimen and, as indicated by the present study, this may not be sufficient. In view of the results reported in this paper there appears to be reason for believing that the paracone may not always pre-

Table 1

Day Stage post-birth in which initiation (i) and calcification (c) of molar cusps was observed.

UPPER								
	M ¹		M ²		M ³		M ⁴	
	i	c	i	c	i	c	i	c
protocone	36	44	44	59	60+	83	?	?105*
paracone	32*	?32*	44	51	60+	60*+	?	105*
metacone	32*	32*	40*	44*	59*	60*+	....	....
stylar cusp A	51	51	59	59	?	105	....	....
stylar cusp B	40	51	?44	59	?	83	?	?105*
stylar cusp D	32*	40	44	59	?	83	....	....

LOWER								
	m ₁		m ₂		m ₃		m ₄	
	i	c	i	c	i	c	i	c
protoconid	15*	21*	36*	36*	44*	44*	60*+	60*+
paraconid	51	51	36*	51	51	59	60*+	60*+
metaconid	36	40	36*	40	44*	59	60*+	60*+
hypoconid	36	40	?36*	?44	59	59	?	83
entoconid	?44	51	?44	59	59	83	....	....
hypoconulid	51	51	?	?	59	60+	....	....

* first occurrence.

cede other cusps in development. Since other marsupials examined, e.g. *Setonix* (Berkovitz 1967b) and *Trichosurus* (Berkovitz 1968) demonstrate that the paracone develops first, this could be interpreted as suggesting the marsupials are polyphyletic with regard to molar formation. An alternative explanation is that the order of cusp development may not be an invariable indicator of the order of cusp evolution of the marsupials in which the metacone develops first. Both *Didelphis* and *Antechinus* differ from other marsupials examined ontogenetically by having a metacone which is the largest cusp on the crown and certainly larger than the paracone (Fig. 1). In *Setonix*, *Trichosurus* and most other phalangeroids, the metacone and paracone are subequal. In most other mammal species previously examined the morphology of the adult crowns (for examples see Butler 1956) shows that the paracone is subequal to or even larger than the metacone. Butler (1967) concludes, from research into the relative growth of the first upper permanent molar in *Homo*, that the antero-buccal areas (i.e. the area of the paracone) of the crown develop before the postero-lingual areas and interprets this as indicating the probable order of cusp origin in phylogeny. However, Butler (1956) had previously suggested (relying on the research of Canalis 1886 and others) that cusp

initiation is the result of a cessation of mitoses at a point on the inner enamel epithelium, the remainder of the crown cusps being subsequently developed in a similar way, while active mitosis, which continues to occur in areas between the cusps, results in enamel deposition in the valleys. Accordingly the cusp destined to be the tallest on the completed crown would presumably be the first to be initiated, and the cusp destined to be the lowest on the crown would be the last to become initiated. Butler's (1956) suggestion would therefore support the hypothesis that the phylogenetic sequence of development of the cusps in *Didelphis* and *Antechinus* may be modified in ontogeny by the great height of the definitive metacone.

It is also possible that the rate of development of the cusps of a crown are not identical. If so, a primary cusp could develop first, but by its surrounding valley developing more slowly than that of a secondary cusp, appear to have developed after the secondary cusp. For example as noted above, in the M¹ of *Antechinus flavipes*, at the 32 Day Stage, the metacone was clearly calcified and better-developed than the paracone. Were this the only stage available, it would be open to interpretation that the paracone had been initiated first, but been slower in development than the metacone. That this is not the case (at least in M²) is demonstrated in this

series by the fact that the metacone was first distinguishable in the 40 Day Stage, while the paracone was not distinguishable until the 44 Day Stage.

The development of the styler cusps reveals a similar problem in interpreting phylogeny from ontogenetic sequence. In the M_1 styler cusp D appears and calcifies prior to styler cusp B. Many Mesozoic fossil therians have well developed styler cusps (e.g. *Pappotherium*), but the basis for determining the homology of these cusps is dubious. Slaughter (1965), Clemens (1968 and 1971), Kermack, Kermack, & Mussett (1968), and others however all recognize the antiquity of styler cusp B, often referred to as the stylocone. It is identified topographically as the buccal cusp generally connected by a crest to the paracone (Fig. 1). This cusp is present in *Antechinus flavipes*. Styler cusp D is posterior to but much larger than styler cusp B. The relatively early development and calcification of styler cusp D compared with styler cusp B in *A. flavipes* appears to be a situation directly comparable with that of the relatively early development and calcification of the metacone compared with the paracone.

Lower molars

In the lower molars of the series, the protoconid invariably developed and calcified first. The metaconid was generally second. In the M_1 the hypoconid developed and calcified before the paraconid. In M_{2-4} the paraconid seems to have developed and calcified in advance of the hypoconid. The hypoconulid and entoconid were usually the last to develop and calcify. In the M_1 however the entoconid developed before the paraconid.

As pointed out by Butler (1956) and subsequently shown by Berkovitz (1968), the protoconid of mammals appears to develop and calcify first (a possible exception in *Setonix* is described by Berkovitz 1967b). No exception would have been expected for *Antechinus* because in that form the protoconid is the largest cusp of each molar (Fig. 1). Röse (1892b) and Berkovitz (1967a, 1968) demonstrate that the metaconid in *Didelphis* and *Trichosurus* is the second cusp to develop in the lower molars, as in *Antechinus*. Butler (1956) reviews other studies (e.g. Woodward 1896, on *Setifer*) which show that in some mammals the paraconid is vestigial or absent in *Trichosurus*. However in *Didelphis* (Röse 1892b) the paraconid develops late, as in the M_1 of *Antechinus*. The relative size of the paraconid in M_{1-4} of *Antechinus* may account for the differences in the rate of development between M_1 and M_{2-4} . In M_1 the paraconid is very reduced in contrast to its condition in M_{2-4} . As noted above, it would be expected to develop later in M_1 . Butler (1956, p. 51) comments in reference to the varying time of development of the paraconid in mammals that "This variation in the time of appearance of the paraconid is in accordance with its relative size . . .".

Berkovitz (1967b) describes cusp formation in the macropodid marsupial *Setonix*. He shows that although the cusp he calls the protoconid of the M_1 develops first, a cusp he identifies as the metaconid on the dP_4 develops first. To account for this he concludes that the larger size of the metaconid of the dP_4 is the reason it develops before the protoconid.

Conclusion

The results reported in this study for the lower as well as upper molars of *Antechinus* support the suggestion of Berkovitz (1967b) that the relative size of cusps is at least as important as phylogeny in determining the sequence of development during ontogeny. It may be that if the cusps are equal in height, ontogeny can reveal phylogeny. Since, however, in most living eutherians in which the paracone and metacone are unequal the paracone is larger, belief that early development of the paracone in these forms supports the contention that this cusp is the ancestral cusp is warranted but does not show conclusively that this is so because the reason for prior development may be cusp size alone. *Didelphis* and *Antechinus* represent a marsupial lineage in which there was selection for a larger metacone. This innovation probably imposed a practical need in these forms to have the larger metacone develop in advance of the smaller paracone.

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